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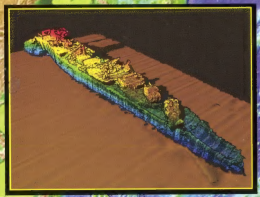

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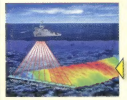

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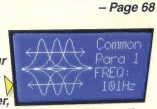

We introduced our new DSP Active Crossover, and 8-channel parametric equaliser last month. Now we get to the fun part – building it! – Page 77

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Editorial Viewpoint

Will 5G mobile networks live up to the hype?

Lately, stories are popping up about how 5G wireless networks are coming soon and will have amazing performance. A few handsets with 5G support are now on sale, and a few 5G networks have been set up in dense urban areas.

While it's certainly impressive technology, providing very high data speeds, 5G networks probably won't replace the 3G/4G mobile networks currently in place. Even if you have a 4G phone, you're likely still relying heavily on the 3G network.

Many mobile devices which are advertised as being 4G only actually use it for data and still use 3G for voice. Voice calls on the 4G network use what's known as "Voice over LTE" or "VoLTE". This isn't supported by all handsets, including even fairly recent 4G-capable models. And even when they do support it, it is often not enabled by default. And for good reason!

My father bought an expensive flagship Samsung phone about a year ago and had incessant problems with call dropouts and unavailability. Often you would dial his number, but his phone wouldn't ring, even though he had good reception. He contacted his carrier on multiple occasions but they were unable to fix the problem. I eventually figured out how to solve this: disable 4G.

If major networks and giant multinational manufacturers still can't get 4G to work properly, it seems premature to be talking about rolling out 5G. I was pretty shocked when I read that the 3G network may be shut down soon; possibly in as little as 12 months! Given how few phones support VoLTE properly, that would be a disaster.

And there are many devices out there which only support 3G, some of them relatively new (alarm diallers, GPS trackers etc) which will simply cease to work if the 3G network is no longer operating.

Then there's the problem of coverage, especially in a country as vast and sparsely populated as Australia. Our 3G operates at either 850MHz, 900MHz or 2.1GHz while 4G is from 700MHz to about 2.6GHz. Both technologies offer reasonable coverage with enough mobile towers.

But 5G operates up to about 39GHz(!). Such high frequencies are not good at penetrating obstacles like trees, walls, roofs etc. So 5G networks will need a lot more 'towers' than 3G/4G networks. That is, if they are to provide the promised higher performance with coverage at least as good as 3G/4G.

And there will also need to be a lot of indoor 'towers' in places like shopping malls to ensure reasonable coverage.

That may be feasible in a densely packed, relatively flat city like Tokyo. But Australia is a different story altogether, and Sydney has some serious topological coverage challenges. Without a massive investment, indoor reception will be very spotty, and there will be plenty of 'black spots'.

You have to wonder what the payback will be for such a massive investment. 4G is already really fast, although I've noticed that the networks have become significantly more congested (and thus slower) in the last couple of years, as data caps have gone up and prices have come down.

I don't know how much of that is congestion in the airwaves and how much is due to other bottlenecks. Faster mobile data networks will do nothing to solve bottlenecks that occur elsewhere.

So I think it's vital that the 3G networks continue to operate until 4G and 5G are fully proven and widespread. And we should adopt a "wait and see" attitude to 5G. There's no point rushing to switch over to it just because it's a new technology. It needs to prove itself useful first.

Nicholas Vinen

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New Zealand 433/434MHz transmitter legality

For your information, the New Zealand Short Range Devices (SRD) General User Radio License (GURL) mentioned in your article on the 433MHz UHF Data Repeater in the May 2019 issue has been superseded. The new one is at: https://gazette.govt.nz/notice/id/2019-go1588

The changes are listed at the bottom, none of which affect the 433MHz band.

While you can operate SRD repeaters under the GURL, the device still needs to meet the applicable standard at a minimum (which can be found at https://gazette.govt.nz/notice/id/2016-go2007).

More information for the requirements can be found at siliconchip.com.au/link/aaqa and it would be at level A1. The supplier would be anyone who manufactures a unit.

Jeremy Logan,
Radio Spectrum Management,
Ministry of Business, Innovation & Employment
Wellington, New Zealand.

Electrical safety should be taken seriously

SILICON CHIP is, without doubt, the best electronics magazine worldwide; I look forward to mine every month.

With regards to your editorial in the February edition regarding servicing of electronic equipment, I always suggest using a workbench wired via an RCD breaker as an absolute safety necessity. Further, all equipment on the bench to be serviced, or currently being serviced, should be powered via an isolation transformer with a single AC outlet for the appliance under test (no Earth pin).

All mains-powered bench test gear should be checked for electrical safety each year (according to AS/NZS 3760, or 3000).

All these precautions will not necessarily protect from fatal electrocution, or even accidents occasioning burns or secondary damage (such as a fall following an electric shock).

Anybody considering building mains-powered devices described in the magazine needs to read, take heed of and understand each of the safety warnings, as well as how to put them into practice for their personal safety. If in doubt, ask your local electrician, or do a short electronics training course, with an emphasis on electrical workers' safety.

Rod Humphris,
Ferntree Gully, Vic.

World's Largest Flip-dot Display Made in Australia

As a very long term reader of your magazine, I always look forward to reading each issue every month. I enjoy the wide topic range and level of technical detail in each article. Keep up the good work!

I'm not sure if it is in your scope, but I think that at least some readers may be interested in what our local Australian companies are doing on the local and world stages. As an example, the Flip-dot project in your April issue immediately made me think of the world's largest flip-dot display we built for a large multinational company in Atlanta (USA).

It's 38m wide and 6.6m high with 55,860 dots and incorporates over 4km of cable. To flip all dots at once (in 100ms) takes 47kW! You can see a video about it at: http://youtu.be/UOwHlk4lM2c

We've made several huge displays, including True-Corp in Bangkok (13 x 3m), Telefonica in Barcelona (10 x 3m) and are currently working on one even bigger than the above!

Our primary focus has been big variable message signs for roads, but we design and make many other things. We design and build all our own electronic assemblies and completed products.

We don't manufacture in China – or even buy components or assemblies from China. We are proudly Australian and do everything to make it here.

You can check out our website to see some of the other things we do, and happy to answer any questions. See: www.adengineering.com.au/product/flip-dot-signs-variable-message-signs/

Peter Harris,
Director, A.D. Engineering International Pty Ltd,
Gnangara, WA.

Stoked about geophone seismograph

I just picked up my April edition of SILICON CHIP magazine and there on page 80 is a Tim Blythman article entitled "Using a geophone with our Arduino seismograph". The article begins, "Reader Michael, from western NSW, kindly sent us a model 20DX geophone sensor, suggesting that this would be a great add-on to our seismograph project".

I'm really stoked that Tim Blythman picked up my suggestion to add a geophone and now I think the unit is definitely worth building. What especially impressed me with this particular Arduino design is the idea of logging seismic data in 4-channel WAV file format.

The MEMS accelerometer used in the earlier design is great for strong motion detection, but not weak local quakes. Viewing and editing WAV data is easy with Audacity or similar software, and since it's already a sound file, one can have fun listening to sped-up seismic signals and the like.

The only thing missing is the addition of precision timing with a GPS module, but I suspect that could be achieved relatively easily by an Arduino whiz. With precision timing, one could set up arrays of the things to log and localise events, and study

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phenomena such as microseismic noise which has a scale size of several tens of kilometres.

Michael Andre Phillips,
Coonabarabran, NSW.

Proposal for lower supply voltages in the home

Here is my perspective on the April 2019 editorial concerning electrical safety. Technology has moved on since Tesla's AC generation and distribution system was adopted as a worldwide standard.

The intrinsically hazardous high-voltage AC system is being rendered unnecessarily dangerous as new solid-state based technology enables intrinsically low voltage devices.

The voltage of the domestic ceiling lighting circuit can now be reduced to a few volts, either AC or DC. Much of the technology incorporated into the new LED lights has been to cope with the relatively high mains supply voltages, when only about 3.5V DC is needed for the LED(s). Fan motors could run at 12-24V DC.

Eliminating 230V AC connectors extends the possible design profiles of globes and luminaires. Fixed switches need not be connected to the luminaires, making multi-way switching and other effects a design breeze with a very low-voltage solid state system.

And why stick with 50Hz? An inductive loop in the ceiling running at 2kHz or so would enable luminaires to simply clip on with no electrical contacts, and battery backup is easily added. Isolated from grid supply, lighting has the potential to become far more reliable. This technology is with us now and only needs manufacturing implementation around a new standard protocol.

Brushless battery-powered power tools using 18-68V DC are breaking the barrier for rotary power devices, Dyson has now stopped the development of mains-powered vacuum cleaner technology.

This smart motor technology is easily capable of being adapted to a 50V DC in-home power circuits for all appliances, and 50V is also enough for hot water and stoves using heavier cables.

So why is an evolutionary migration to low voltage, intrinsically safe, home electrical distribution system not taking place?

I don't see any manufacturing difficulties in transitioning from the old system to a new one but more the legal, prescriptive nature of building and wiring requirements in most countries including Australia, discouraging manufacturers from offering such products on an evolutionary basis.

Technology has moved so far and so quickly that it could now be argued that our current prescriptive electrical laws may contribute to unnecessary future deaths and injuries from needless electrical hazards.

Kelvin Jones,
Kingston. Tasmania

Nicholas comments: while lighting and some appliances could run from lower voltages, the current requirements of many appliances at lower voltages (eg, washing machines, drivers, ovens, coffee machines) would be impractically high. In countries with 110-120V mains, some of these machines are already a challenge to power.

Espresso machines are a good example. Units sold in countries with 115V mains often need to use less powerful heating elements to keep the current draw modest. Some domestic espresso machines need 15A outlets for full performance even in Australia.

Overseas, those same machines do not work as well, not being able to draw even the 2300W that's available from a mains socket here.

Regarding battery-powered vacuum cleaners, I have found their performance to be inferior to mains-powered vacuums, suitable only for some jobs. After vacuuming my car using just a Dyson for a few months, it started smelling bad. One quick pass with a mains-powered vacuum (no flat battery halfway through the job!) had it clean again.

I'm not saying low-voltage, battery-powered vacuum cleaners are bad; they certainly have their uses. But they are no replacement for a mains-powered vacuum with much more powerful suction.

Tips for soldering battery packs

I have been making up battery packs by soldering (with great care!) NiMH batteries together. These batteries (like some other items) are nickel-plated which leads to frustration, as the rosin flux in standard solder is not adequate for the job.

Different fluxes suit different metals, and I heard from someone that phosphoric acid would work as a flux. Phosphoric acid is available in dilute form as 'rust converter' – one common brand available in Western Australia is Ranex, which is 35% phosphoric acid.

So I decided to try using this as a flux for soldering to the batteries. Phosphoric acid is nasty stuff, especially on skin, so safety precautions (gloves, goggles etc) must be observed. And you need good ventilation, since it can

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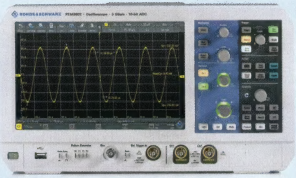


emit fumes after being applied to the surface you wish to solder.

After applying phosphoric acid to the nickel-plated connectors, I've found that the soldering process is easy, at least using tin-lead solder. I haven't tried lead-free solder yet.

Soldering iron contact with a battery should be limited to a few seconds or less, to avoid damaging the battery. I've found that a hot soldering iron with a bare few seconds contact with the battery has solved many of my battery-pack making problems.

E. McAndrew,
Capel, WA.

CablePI can give a false sense of security

On page 8 of the April 2019 issue, in a comment on a letter from one Paul Smith, reference is made to the Tasmanian CablePI. This device is quite heavily touted in Tasmania as an electrical safety device. How this product works is beyond my ken.

But I recently was asked to look at a washing machine that gave out 'tingles'. When I confirmed that the appliance was OK and suggested that the house earth wiring might be at fault, the customer stated the house was electrically safe because the "CablePI said so".

My point is that this device leads householders to believe all is well when it may not be. It might be a worthwhile exercise by SILICON CHIP to run your eye over the CablePI. Regards and thanks for an excellent magazine.

Don Selby,
Tasmania.

Comment: it does seem unlikely that such a simple device, plugged into a single powerpoint and connected nowhere else, could pick up all possibly hazardous wiring faults.

It could only really detect when the Active-Neutral voltage is lower than normal, or the Neutral-Earth voltage is higher than usual.

However, depending on the nature of the fault, these may only occur when a high load current is flowing through the house wiring. And a completely open Neutral would not leave any power to operate the device, while still constituting a hazard.

Another way to build the DAB+/FM/AM radio case

I built your DAB+/FM/AM receiver project (January-March 2019; siliconchip.com.au/Series/330) and thought that the following information might be helpful to others.

Rather than using 25mm and 32mm long screws through the front and back of the case, as shown in Fig.3 on page 43 of the March 2019 issue, I instead used four 50mm long M3 screws through the front. All the spacers can be fitted to these screws and then you just need 4-6mm long M3 screws to hold the back on. I got the 50mm screws at my local hardware shop.

Ray Saegenschnitter,
Huntly, Vic.

Comments on 737 crashes, Avalon air show etc

The Editorial Viewpoint in the May 2019 issue of SILICON CHIP cannot be ignored. I do not agree that "crippleware" is to blame for the 737 Max disasters. I believe that the management of both Boeing and the FAA are ignorant and arrogant, and are to blame.

Both Boeing and the FAA have good reputations. Why then this stupidity? The answer is that neither Boeing nor the FAA are the same organisations of years ago.

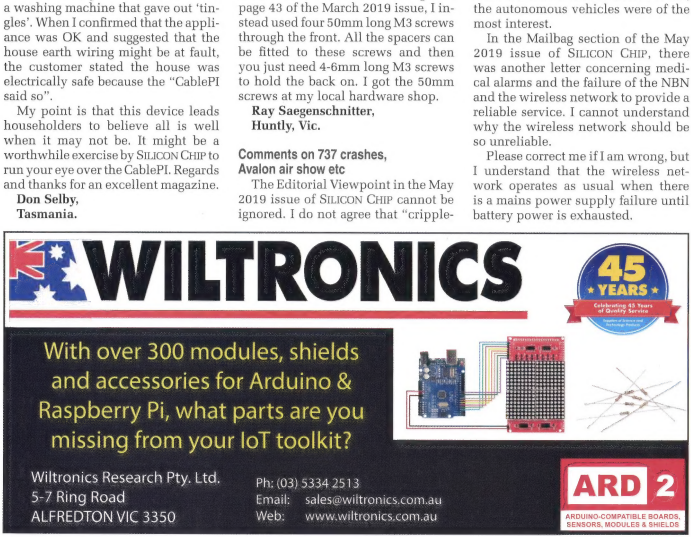
Like all organisations, the original staff have been replaced by new staff in most of the positions. These new staff have failed. Invariably and in so many ways they are not the same people as those whom they replaced.

Referring back to the subject of "crippleware", the best way to handle manufacturers who sell such products is simply not to buy them. They will soon get the message.

The article on the Avalon air show by Dr Maddison in the April issue sure is huge. This show highlights just how important electronics is to the military. Everything mentioned in the article excepting the lightweight armour relied on electronics. For me, the autonomous vehicles were of the most interest.

In the Mailbag section of the May 2019 issue of SILICON CHIP, there was another letter concerning medical alarms and the failure of the NBN and the wireless network to provide a reliable service. I cannot understand why the wireless network should be so unreliable.

Please correct me if I am wrong, but I understand that the wireless network operates as usual when there is a mains power supply failure until battery power is exhausted.



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But why does it have to be this way? Surely, transmission consumes far more power than reception.

So if the mains power has not been restored within an hour, the wireless network should only respond to the 000 emergency number and ignore any normal calls. This would extend the running time of the network considerably and hopefully, mains power will be restored before the batteries are exhausted.

The only changes that would be required are to upgrade the firmware of the network and to make 000 the last contact of the emergency calling machines.

George Ramsay,
Holland Park, Qld.

Comments: ultimately, all organisational failures can be blamed on management. But engineers (both aviation and software) made poor decisions, contributing to those two airliners crashes.

*It's hard to believe how many mistakes were made. Read this article and weep for the stupidity: **siliconchip.com.au/link/aaqc***

Keep in mind that since SILICON CHIP is an electronics-themed magazine, our coverage of the Avalon air show is slanted towards electronics and technology. No doubt there were impressive exhibits at the show which we did not cover as they were not electronics-related.

Your idea of extending the time that mobile networks can operate after a widespread power outage is a good one. We're not sure if it such a system has been implemented – we guess not.

However, it seems likely that in a major disaster, the batteries would still run out eventually. The problem is that there are more mobile towers than exchanges, and they have less space for batteries/generators.

Yet another request for more preamp inputs

I was thrilled to see the new preamp project, with much-needed features like remote (linear) volume control and a true-bypass tone control section, but what is this – only three inputs? To me seems to be a prime example of "don't spoil the ship for a ha'p'orth of tar".

I would be more inclined to build this project if it had, say, four inputs. Or even a few more. I can easily use four inputs without having an over-the-top range of devices to connect in my lounge.

I need at least inputs for CD/SACD player, turntable preamp, TV, DVD/Blu-ray and a spare for portable players such as iPods/computers/etc without having to fumble around the back of the unit.

Three inputs seem just so stingy. I'm looking forward to a revised version with more.

Geoff Wood,
Wellington, NZ.

Response: we are planning to expand the number of inputs to six in a future article.

Electret microphone crystal set works well

I built the crystal radio set using an electret microphone as a detector that you published in the Circuit Notebook section of the February 2019 issue (**siliconchip.com.au/Article/11408**). It's a bit of a rat's nest on a breadboard, but I became quite excited when it burst into life earlier today.

I purchased the microphone capsule, antenna coil and rod from Jaycar. The tuning capacitor was salvaged from an old AM/FM tuner module and the earphone came from a Western Electric tone phone (a gift from an internet friend in the USA).

I can pick up seven local stations here in Brisbane, and 1116kHz 4BC comes booming in during their daytime power broadcast of around 17kW. The transmitter is at Nudgee and I live in New Farm, about 15km away. It's a good result for such a basic lash-up!

Austin Hellier,
New Farm, Qld.

NBN does not cater for emergency calls

I am amazed that the Editor did not add a footnote to the letter (David Williams, April 2019) concerning the loss of emergency phone calling on the NBN.

It's a good object lesson in keeping technical matters out of the political arena wherever possible. When the NBN was first announced, a caller to ABC Melbourne's morning program highlighted this very aspect of the NBN.

The presenter (a stand-in, not the regular person), shut down the caller brutally and dismissively. His bias in not wanting to hear anything critical of

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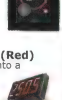

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that government's program was crystal clear. Nothing bad could be said that day about the NBN.

Yet the program to replace a copper voice network with a fibre data network over which we will carry voice is a huge and revolutionary program. To attempt to replace in just 15 years what has taken almost 150 years to evolve is 'crazy brave'.

One of the costs of doing it is the loss of the 'baked in' emergency phone system. If only we could have reasoned debates about national issues, and so have most of us understand much of this revolutionary program.

While the whole NBN system does away with the fail-safe phone system, your correspondent attaches his ire to the HFC variety. Paradoxically, the HFC system does provide a solid copper connection into the home, and in theory, at least, could provide its own power supply.

That will never be done, of course, and even with HFC, we have no choice now but to find alternative strategies for emergencies. Relying on mobile phone technology is not an intelligent emergency strategy.

Max Williams,
Ringwood North, Vic.

Comment: we did not add a footnote to that letter because the implications should be clear to anyone reading that letter (and indeed, this one).

Combining two preamp designs

I have recently finished building the Studio Series Stereo Preamplifier from October 2005 (siliconchip.com.au/Article/3203).

I modified the circuit to use NE5532 op amps instead of OPA2134s, as they are easier to get and cheaper, with similar performance. I also changed the component values around them to those specified for the Ultra-LD Stereo Preamplifier, November & December 2011 (siliconchip.com.au/Series/34).

The reason I didn't simply build the 2011 design is that I need more than three stereo inputs. The 2005 board suited my requirements, with six inputs.

I did not fit the 1MΩ resistors at the input to the preamp, and I am fitting 6.8kΩ resistors between the wiper and ground ends of the 10kΩ logarithmic volume control potentiometer (VR1). I calculate that this will provide a suitably low impedance to the input of the second op amp, in line with your 2011 article's tweaking section. To make all these changes, I had to cut several tracks on the PCB.

I am building two of these preamplifiers. The first is to use with a modified Hifi Stereo Headphone Amplifier (September-October 2011; siliconchip.com.au/Series/32). To simplify power supply arrangements, the headphone amp will be run off a ±15V supply.

The second preamp is used in conjunction with powered studio monitor speakers. It will be interesting to see how the preamps perform once both projects are up and running.

Many thanks for a great magazine. My copies date back to 2002. I hope that your interesting and well explained designs can continue and you are not forced to restrict/dumb down projects to plug-pack only operation. I fear this may be the case after reading your April 2019 editorial on complaints about publishing mains-powered designs.

Richard Kerr,
Cessnock, NSW.

Comment: the only real benefit of using OPA2134 JFET-input op amps in the Studio-series Preamp over the good old NE5532s is that they allow the relatively high (1MΩ) input impedance, but this is not required for most equipment.

Suggestions for UPS battery replacement

I saw Peter Allica's request in the Mailbag pages of the March issue, for help with information on Datasaver UPSes, as he was planning to upgrade them to use modern batteries.

Googling "Datasaver" yields a lot of irrelevant hits, so that's not going to be an easy avenue. I tried a reverse lookup of the old phone number, it's now in Mount Nelson and looks residential. So we've struck out there.

But, a few days ago, I was looking at Jaycar's latest flyers online. They have just released a range of $LiFePO_4$ batteries they say can be used as a straight replacement for lead-acid batteries. I have no additional information on these products apart from what's in Jaycar's flyers and website where a brochure can be downloaded.

I am in a similar boat to Peter. It appears that my UPS needs its third SLA battery. It died about the time of the bushfire scare here. I am trying to find out whether I could put one of these new $LiFePO_4$ batteries into my UPS;

first, I have to ascertain if that is the only fault.

On face value, it would seem we can both use these new batteries; they cost roughly twice what I paid for the SLA replacement 18 months ago. However, further information would reassure me.

David Morton,
Geeveston, Tas.

Up-rated inverter suggestion for the UPS project

You used a Giandel inverter in your UPS project (May-July 2018; siliconchip.com.au/Series/323), which I am yet to build.

When I went to the Giandel website, I found that it was evasive on details. Also, the prices were suspiciously low for the specifications given. I also found some people on TheBackShed forum complaining about the build quality of Giandel inverters (siliconchip.com.au/link/aagb).

Are you planning on doing an updated project, hopefully with options for a higher power version? What about using Jaycar Cat MI5718, rated at 2200W?

I have had trouble starting my domestic refrigerator and freezer from other 12V and 24V inverters. I have read several readers letters in SILICON CHIP and understand that the problem is the extremely high starting current that the induction motors have.

I tried a severe test with the Jaycar Cat MI5718 inverter. I turned both my (130W) refrigerator and (90W) freezer off and cabled them both through a switch to the Jaycar inverter, which was running without power saving, to prevent the soft-start feature from working.

When I turned the switch on, the Jaycar inverter started both devices at the same time, quiet as a mouse, no complaints at all. You may be able to patch into the remote control to be able to start and stop the inverter, as you have done with the 433 MHz remote control mains switches.

I shall follow the project with interest.

Patrick Berry,
Turramurra, NSW.

Response: we chose the Giandel inverter because its price was very good for the specifications given, and we have not had any trouble with it in our testing.

Note that with our UPS, since it is usually switching over to inverter power just after mains power has failed, the devices are already running and so their 'inrush' at switchover should not be too severe.

The Jaycar unit you mention does look very good, and given its specifications, the price is not unreasonable. It is somewhat more expensive than the one we used in our UPS project.

It probably wouldn't be necessary to figure out how to control that inverter remotely since it has a power switch which can be set permanently to on. You could then rely on the inverter's under-voltage lockout feature to shut it down when the battery is flat. And the built-in solar charger is a really nice feature.

Individual responsibility is an outdated concept

It was interesting to read that someone had felt your magazine was unsafe, due to some projects being mains powered (Editorial, April 2019). What surprised me is that you seemed surprised at the allegation.

Our country has a legal system now in place where self-responsibility no longer exists; the government believes the average person is too stupid to be allowed to do anything without constant supervision, hence the Nanny State.

No matter what the situation, if something goes wrong then the immediate action is to find out where blame can be assigned, with zero effort, rather than putting effort into finding remedies. It's far more important to sack someone because vengeance is what matters.

Every passing day proves Douglas Adams was a prophet.

Anon.

Comments on letters in the March issue

I wanted to comment on a few items raised in the Mailbag section of recent SILICON CHIP magazines, mainly letters from the March 2019 issue.

Regarding LED lights which flicker when used with a dimmer, I have had this problem and so has one of my friends. We tried a range of different commercial dimmers, but it made no difference which one I used. The LED lights still flickered at times.

Regarding the Majestic loudspeaker cabinet, you are right that loudspeaker design is a much more complex subject than it seems. I suggest that your correspondent buys a copy of Vance Dickason's "Loudspeaker Design Cookbook". It's fantastic.

There are also many loudspeaker design computer programs available; some free, some at low cost. I have used them and they are also fantastic.

Regarding "Joseph Lucas is a modern hero" by Dave Dobeson; while we can be smug about the early electrics in cars compared to what we have now, it is worth remembering that back in the day, they started from scratch. Today's automotive electronics is more evolutionary and builds on decades of experience.

Our 'older' vehicles do not use the Kettering System but it served well in millions of cars for many years and also in aeroplanes. Yes, analog engine management systems present many hassles today, as do older, high-quality audio amplifiers/receivers, stoves with electronic controls and similar items where the IC's are not available anymore.

As for your editorial in that issue, "We all deserve a right to repair", I couldn't agree more. Independent automotive workshops are having an industry-wide battle about this at the moment.

The ACCC has taken some action, but I am not sure if it is broad enough to satisfy the workshops' needs. The availability of expertise is a different question and always will be – as it is for any discipline.

Regarding Fred Wild's comments on the usefulness of an automotive Low Coolant Alarm, it is an excellent idea. The modern practice of using temperature warning lights or gauges does not cover the situation where a water leak leaves the temperature sensor in free air, so it is reading almost no temperature at all, even though the engine is overheating.

Another good solution is to fit a device like the "Engine Watchdog" which uses a temperature sensor clamped to the hottest part of the engine block.

It is linked to a temperature display and warning buzzer which can be set to any particular temperature. It can also be used to control additional cooling fans etc. It is not dependent on the presence of coolant so it could save expensive repairs.

Ranald Grant,
Brisbane, Qld. SC

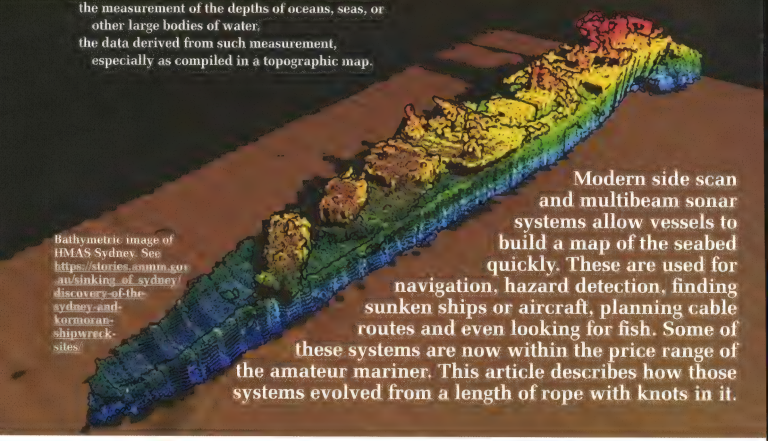
Bet you've never heard of

bathymetry *[buh-thim-i-tree]*

noun

the measurement of the depths of oceans, seas, or other large bodies of water,
the data derived from such measurement, especially as compiled in a topographic map.

by Dr David Maddison



Bathymetric image of HMAS Sydney. See https://stories.snmm.gov.au/sinking_of_sydney/discovery-of-the-sydney-and-kormoran-shipwreck-sites.

Modern side scan and multibeam sonar systems allow vessels to build a map of the seabed quickly. These are used for navigation, hazard detection, finding sunken ships or aircraft, planning cable routes and even looking for fish. Some of these systems are now within the price range of the amateur mariner. This article describes how those systems evolved from a length of rope with knots in it.

Today, bathymetric data is obtained mostly by electronic techniques, either via acoustic systems (sonar, sound navigation ranging) or to a lesser extent, optical systems (lasers or reflected sunlight).

Seabed imaging and mapping, from shallow coastal areas to deep oceanic waters, is important for the following purposes, among others:

- navigation of vessels in shallow water.
- submarine navigation.
- knowing where to drop anchor, as the water cannot be deeper than the anchor chain is long.
- mapping the location of rocks, reefs and other marine navigational hazards.
- locating shipwrecks for historical purposes/archaeology or for hazard avoidance, salvage or recreational diving.
- searching for downed aircraft, such as Malaysia Airlines flight MH370, presumed crashed into the sea.
- placement of oil rigs and underwater cables and pipeline.
- knowing where to dredge to create or restore shipping channels.
- recovery of underwater mineral deposits.

Since the oceans cover around 71% of the Earth's surface, these mapping tasks are much more significant, and certainly more difficult than land mapping. In most areas, the ocean bottom is not visible and depth measurement is difficult.

Apart from taking accurate depth measurements, it is also important to accurately know the location of each depth reading (latitude/longitude).

This benefits enormously from the development of GPS and other satellite navigation systems. We published a detailed article on augmented GPS technology, accurate to less than a metre, in the September 2018 issue (siliconchip.com.au/Article/11222).

In nautical terminology, "sounding" means the measurement of depth by any means, using sound waves or otherwise. This could be done using a long stick, a rope or laser light. The laser airborne depth sounder (LADS) was an Australian invention, first deployed in 1977.

State-of-the-art bathymetry systems are usually based on side scan or

BATHYMETRY

multibeam sonar, using an array of transducers and powerful computers to form 3D images of the seabed or river bed under a ship, or a towed sonar array. But electronic/acoustic water depth measurements go back over 100 years and simpler methods have been in use since antiquity.

Fig.1 shows a comparison of the three most common modern sounding techniques. We'll now describe the history of sounding techniques, starting from the beginning and proceeding to the present and the latest sonar and LIDAR systems.

Historical bathymetry

Seabed mapping has been performed since ancient times. It was practised by the Ancient Egyptians, who used poles and ropes, and also the ancient Greeks and Romans, who used a rope with a weight on the end to determine depth, known as a lead line or sounding line – see Fig.2.

Such lines were the primary method of determining seabed depth right up until the 20th century, and are still used today a backup to electronic depth sounding systems (sonar).

In the 19th century, attempts were made to automate the lead line sounding process. These employed mechanisms which would indicate when the seabed had been reached.

Among these were Edward Massey's sounding machine, employed by the Royal Navy, who purchased 1750 of them in 1811. There was also Peter Burt's buoy and nipper device.

These devices were designed to work up to around 150 fathoms' depth (275m). In the late 19th century, the installation of undersea telegraph cables created a much greater demand for depth measurement.

Lord Kelvin (then Sir William Thomson) developed and patented

Fig.2: a lead line or sounding line showing different markers at traditional depths of 2, 3, 5, 7, 10, 13, 15, 17 and 20 fathoms. A fathom is today defined as exactly six feet or 1.8288m. Fathoms and feet are still used on US nautical charts whereas other countries use metres.

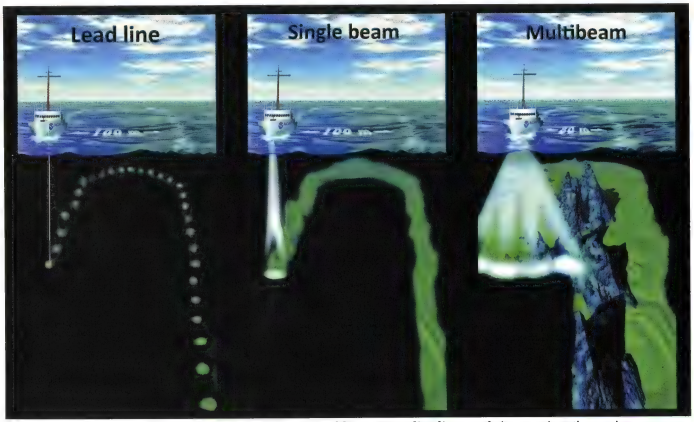
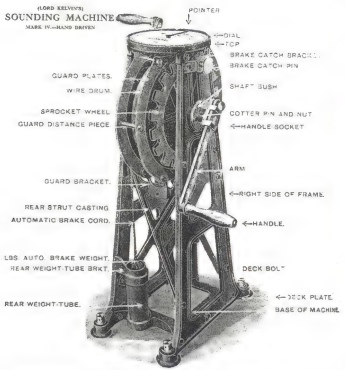


Fig.1: three different sounding methods in use today. A lead line or sounding line, used since ancient times, gives spot measurements; a single beam sonar is capable of giving continuous measurements although some still give spot measurements; multibeam sonar can scan a wide area in one pass and can quickly build up a seabed map. Laser systems such as LADS give similar results to multibeam sonar.



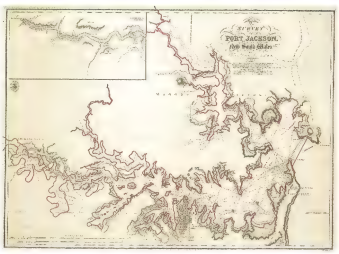


Fig.4 (above): a depth map of Port Jackson (Sydney) made using sounding lines from Roe's 1822 survey. Note how the soundings appear as tracks indicating the path of the vessel.

Fig.3 (left): one version of Lord Kelvin's mechanical sounding machine.

his device in 1876, shown in Fig.3. It featured piano wire and a hand-cranked or motorised drum for winding. There was a dial on the drum to indicated the length of line let out. This device and later versions of it were in use with the Royal Navy until the 1960s.

Using a sounding line, maps were made by periodically measuring the depth while at sea and mapping those depths in relation to landmarks (if in coastal areas) or through latitude and longitude measurements taken with a chronometer or sextant if at sea – see Fig.4.

Use of sound waves

Sounding lines are impractical for very deep water due to the amount of line that has to be reeled out. The survey vessel usually has to be stationary but the line can be swept away by currents, and it is sometimes difficult to tell when the bottom has been reached. It's a very slow method, even when it's feasible.

For these reasons, alternative means were sought to measure depth and these were developed in the early 20th century.

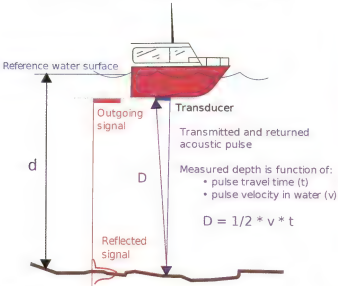


Fig.5 (above): the basic principle of echo-sounding.

Fig.6 (right): the Fessenden Oscillator transducer, initially used for detecting nearby icebergs and later for making depth measurements.

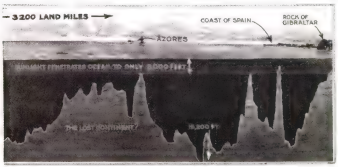


Fig.7: the ocean floor between Newport, Rhode Island (USA) and Gibraltar, as determined by the USS Stewart in 1922. This survey used the Hayes Sonic Depth Finder and found what was thought at the time to be the lost continent of Atlantis. From Popular Science, May 1923.

Fig.8: a map of the soundings taken by the USS Stewart across the Strait of Gibraltar in 1922.

The use of sound to detect objects in the water was first recognised by Leonardo da Vinci in 1490. He is said to have placed his ear to a tube which was immersed in water and listened for distant vessels.

The fact that sound waves travel at a known velocity in water and are reflected from solid surfaces such as the seabed is the basis upon which echo sounding and sonar were later developed.

The basic principle of echo sounding to determine depth is that an acoustic pulse is emitted from the device and it travels through the water column at a predictable speed. It strikes the seabed and is reflected to a receiver (microphone). At a basic level, the depth of the water is then computed by taking half of the return time for the pulse and multiplying by the speed of sound in water.

For example, if a pulse took 0.8 seconds to return and the speed of sound in water was 1500m/s, the water depth would be 0.8s x 1500m/s ÷ 2 = 600 metres.

In practice, sound velocity can vary slightly in water due to differences in salinity, temperature and depth. These effects can and usually are taken into account. In general, a 1°C increase in temperature results in a 4m/s increase in the speed of sound, an increase in depth of 100m results in an increase of 1.7m/s and an increase of one part per thousand of salinity results in an increase of 1m/s.

Note that temperature usually decreases with depth, causing the speed of sound to decrease, but at the same time the speed increases with depth (or pressure). The combination of the two effects can result in a sound velocity profile that decreases in the first few hundred metres, then increases at greater depth.

Early echo-sounding devices

The earliest acoustic depth measuring devices were known as echo ranging devices or fathometers. Today it is known as sonar ("SOund Navigation And Ranging"). These devices used a single acoustic 'beam' to measure the seabed depth and as a consequence, can only measure the depth directly beneath a vessel, just like the lead line (see Fig.5).

In 1912, Canadian Reginald Fessenden developed the first electronic or electromechanical acoustic echo ranging device (Fig.6). It used a mechanical oscillator that was similar in design to a voice coil loudspeaker. It could

Fig.9: the Dorsey Fathometer as installed on the SS John W. Brown, a US Liberty Ship during World War II.

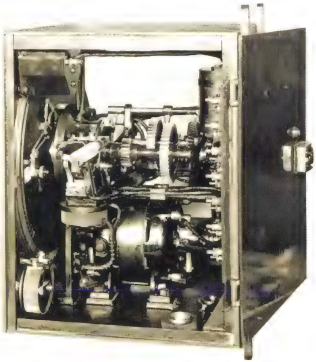


Fig.10: an internal view of the head unit of a Dorsey Fathometer from the 1925 operator's manual. Note the electromechanical nature of the componentry. There were also other electronics boxes.

Fig.11: the Dorsey Fathometer in use, 1931.

Open source seafloor mapping software

Open source software called MB-System is available, which can processes sonar data to create seabed maps. It supports most commercial data formats. The system operates on the Poseidon Linux distribution or macOS.

Readers could create their own seabed maps from publicly available data or perhaps with their own data, if they have a boat with an echo sounder. You can download it from **siliconchip.com.au/link/aanx** or see videos on their YouTube channel at **www.youtube.com/user/MBSystem1993**

generate a sound wave and then it could be immediately reconfigured as a type of microphone, to listen for echos.

This system was first tested in Boston Harbor, then in 1914 off Newfoundland, Canada (the RMS Titanic had recently sunk in that area). The machine was shown to have had an ability to detect icebergs out to about 3km, although it could not determine their bearing due to the long wavelength used and the small size of the transducer compared to the wavelength.

In this mode of operation, the device relied on the propagation of waves horizontally through the water, but it was incidentally noticed that there would sometimes be an echo which was not associated with any iceberg. These were from a vertical wave reflecting off the seabed. This was the impetus behind the idea to use the device for depth sounding.

The device was also shown to be capable of use for underwater telephony. The machine operated at 540Hz and later models operated at 1000Hz and 3000Hz, and were used up until and during World War 2, for detecting vessels and

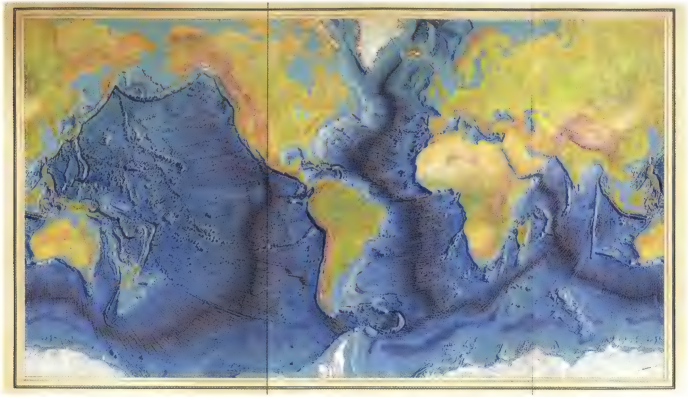


Fig.12: a hand-painted map by landscape artist Heinrich C. Berann, based on the 1950s and 1960s sounding work of Bruce C. Heezen and Marie Tharp. It shows a continuous rift valley along the Mid-Atlantic Ridge along with similar structures in the Indian Ocean, Arabian Sea, Red Sea and the Gulf of Aden. Their discovery led to the acceptance of the theory of plate tectonics and continental drift. (US Library of Congress control number 2010586277)

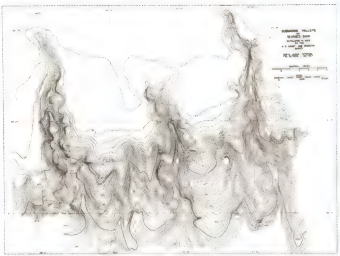


Fig.13: topological map from the US Coast and Geodetic Survey (C&GS; the predecessor of today's NOAA), showing one of the first comprehensive surveys of the continental slope of the USA. It was produced in 1932 with the most advanced echo sounding and radio acoustic ranging navigation systems available at the time. Radio acoustic ranging involved detonating an explosive charge near the ship and listening for the arrival of sound waves at remote locations, recording their time of arrival and reporting it back to the ship by radio.

mines. No examples are known to exist today.

Fessenden won the 1929 Scientific American Gold Medal for his achievement. A detailed description of the device that was written in 1914 can be seen at siliconchip.com.au/link/aanw

In 1916 and 1917, Frenchman Paul Langevin and Russian Constantin Chilowsky received US patents for ultrasonic submarine detectors, one of which used an electrostatic "singing condensor" transducer and the other used piezoelectric quartz crystals.

In 1916, British Lord Rutherford and Robert Boyle were also working on the use of piezoelectric quartz crystals in transducers to detect submarines. Following this, in 1919 and 1920 the French performed sounding surveys using their prototype device, then in 1922, surveyed a telegraph cable route from Marseilles to Philippeville, Algeria. This was the first claimed practical use of echo sounding.

Fig.14: a river survey using single beam sonar readings to determine the depth profile of a river where other methods would be unsuitable (Source: Ayers Associates).

Also in 1922, American Dr Harvey Hayes tested his Sonic Depth Finder on a US Navy ship. It used a Fessenden Oscillator and was said to be the first device capable of deep water sounding.

On one of its first tests on the USS Stewart, the ship sailed from Providence, Rhode Island to Gibraltar in nine days, during which 900 soundings were taken between 9-3200 fathoms depth (16-5850m) – see Figs.7&8.

The soundings were even taken while the vessel was

Fig.15 (above): an image of a steamship wreck in the Gulf of Finland, 33m deep, made with a StarFish sonar.

Fig.16 (right): the compact, portable StarFish 452F sonar kit. The towed body or towfish is yellow and 38cm long. The resulting data is displayed on a PC. It has a range of up to 100m on each side; larger systems have greater range and performance. This system is available online for US $6637, excluding GST and delivery costs. It operates at 450kHz. Full-size towfish are 1-2m long.

Fig.17: an image of a World War 2 era PB4Y bomber in 53m of water in Lake Washington, USA made with StarFish side scan sonar.

cruising at 23 knots. That voyage was an enormous success, with many undersea topography discoveries made and, in a time before highly accurate means of navigation such as GPS, US Navy officials said they expected to be able to navigate across the oceans using such soundings to observe undersea topography.

The Sonic Depth Finder was operated by adjusting the interval between when the signal being transmitted and the echo of the previous signal being received. When a transmitted signal and a received signal coincided, that corresponded to a calibrated dial position indicating the depth.

Despite the overall success of the USS Stewart voyage, the instrument relied on operator skill to a significant degree and had inherent limitations. So it was not regarded as suitable for precision surveys. This led to the development of a new device, considered to be the first practical echo sounding machine. It was called the Dorsey Fathometer, invented by American Herbert Dorsey in 1923.

One advantage of this device compared to others is that a ship could take soundings at full speed. One model of the device could measure depth between 8 and 3000 fathoms (15-5500m). See Fig.9, Fig.10 and Fig.11.

It was said to have an accuracy of 7.6cm (three inches), but it's unlikely that this could be achieved in reality due to variations in sound velocity through the water and so on. The display consisted of a spinning neon light which would flash at the point on the dial corresponding to the measured depth.

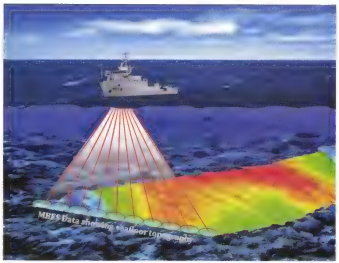


Fig.18: multibeam echo sounding uses narrow beams. This shows the sort of topography which can be generated. (Source: NOAA Photo Library, Image ID: fis01334)

Early sonar devices were too large to put on smaller vessels, which were needed for harbour work, so up until the 1940s, lead lines were still used for such survey work. Eventually, the sonar equipment became small enough that it could be installed on smaller vessels.

Along with improvements in the electronics came improvements in their transducers. The operating frequency was increased beyond the audible range, into the ultrasonic region, and transmitters and receivers shifted from electromechanical to piezoelectric devices. Improvements in recording also enabled continuous measurement of depth, rather than just periodic spot measurements.

During this period, many discoveries were made about underwater geological structures, such as the mid-Atlantic Ridge, seamounts and many other geological features, especially after WWII. Before this, the seabed was thought to be mostly dull and featureless.

These discoveries, mostly during the late 1950s and early 1960s, helped lead to the development of the theory of plate tectonics, which states that the continents are on geological "plates" that drift due to motions between the plate boundaries (see Fig.12). It is now accepted as fact.

Modern echo sounding technology

In modern echo-sounding or sonar, there are three main categories: single beam, side scan and multibeam.

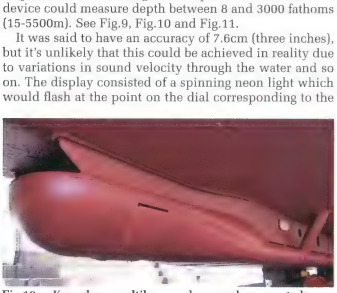


Fig.19: a Kongsberg multibeam echo sounder mounted on survey vessel. Note the partially visible person at bottom right for an idea of its size.

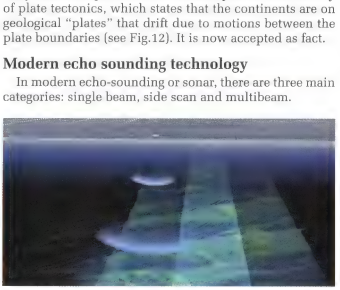
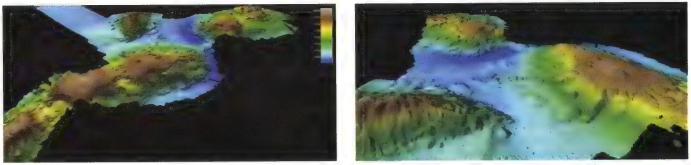


Fig.20: a typical survey pattern for multibeam sonar. The paths overlap on purpose, to give improved confidence in the data. (Courtesy: Geoscience Australia)



Figs.21: multibeam maps of seamount chain discovered by the CSIRO in 2018, 400km east of Tasmania. The seamounts rise about 3000m above the seabed, which is 5000m deep. These are important areas of biodiversity.

Single beam sonar is the traditional type and is a proven, relatively inexpensive technology. Such devices are usually mounted on the hull of a vessel. They give depth information from a single 'spot' beneath a vessel but no information is given as to what is off to the side. They are commonly used for navigation purposes.

Single beam sonar can also be used for mapping and has the advantage of lower cost, less data to deal with and the ability to be used in shallow and otherwise inaccessible waters such as rivers, where multibeam sonar is not practical. But it gives much less complete information than other methods (see Fig.14).

Sound waves generated by a single beam sonar system are typically at 12-500kHz and the approximate sound beam width (shaped like a cone) is 10-30°, depending on the transducer used.

A frequency of 200kHz is typical for depths under 100m, and since higher frequency sound is attenuated over shorter distances, 20-33kHz is typical in deeper water. Lower frequencies are also better in turbulent water.

Additional processing performed on single beam sonar data may include taking into account the vessel attitude (roll, heave, pitch and yaw), tides and speed of sound in the water at the location. The spatial resolution of mapping data obtained with single beam sonar depends on factors such as the survey route and depth of water.

Side scan sonar

Unlike single beam sonar which transmits acoustic energy downwards, side scan sonar transmits acoustic energy to the side. It does this (usually) from a towed underwater "pod" known as a towfish (Fig.16).

A fan-shaped beam is emitted from both sides of the towfish. Rather than just receiving one return signal from one spot after a pulse, like single beam sonar, many return echos are received from multiple distances off to each side after each ping.

The main purpose of side scan sonar is to produce images of the seabed, rather than mapping data. Images are generated based upon the amount of reflected sound energy as a function of time on one axis and the distance the towfish has travelled on the other axis (effectively, the next set of ping data).

The returned data is analysed and processed to produce a picture-like image (see Figs.15 & 17). The seabed and objects on it, such as ship or aircraft wrecks or obstructions, can be imaged well. However, this type of system is not so suitable for accurate depth data. No image is produced in the central part of a side scan image, which is between the two side beams.

Man-made objects, typically containing metal which reflects sound energy well, show up brightly on the image. Sound frequencies in the range of 100-500kHz are typically used. One such device of note is GLORIA (Geological LOng Range Inclined Asdic) which is an extremely long-range system that can scan the seabed 22km out to each side, and has a ping rate of twice per minute.

Multibeam sonar

Multibeam (swathe) sonar is similar to side scan sonar but the data is processed differently. Whereas side-scan sonar images are produced primarily based on the strength of the echos, with multibeam sonar, the travel time of the echos is measured instead. This type of sonar is mostly used for mapping (see Figs.18-22).

A multibeam sonar system transmits a broad, fan-shaped pulse of sound energy like a side scan sonar, but "beamforming" is used for transmitting and receiving the data,

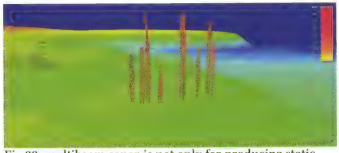


Fig.22: multibeam sonar is not only for producing static images such as of the seabed. It can also image dynamic phenomena such as methane gas seeping from the seabed in the Gulf of Mexico. (Source: NOAA, Image ID: fish2946, NOAA's Fisheries Collection 2010)

Fig.23: the 208 x 244 x 759mm EdgeTech 6205s hybrid multibeam and side scan sonar instrument. It operates at 230, 550, 850 and 1600kHz and has a range of 250m at the lowest frequency and 35m at the highest, used for side scan. For multibeam work at 230kHz, it has a swathe width of 400m.

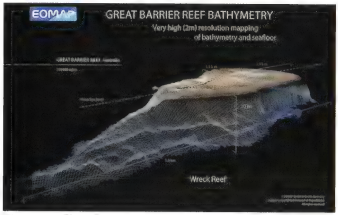


Fig.24: satellite-derived bathymetry image of an island in the Great Barrier Reef. (Courtesy EOMAP)

yielding narrow slices of around 1°. There are therefore a large number of independent beams in a multibeam sonar and for each one, there is a known angle and return time.

Knowing the speed of sound in the water being surveyed and the angle of the received beam, it is then possible to determine the depth and range of the object that the signal bounced off, and thus a map of the seabed can be created. Data has to be adjusted for heave, pitch, roll, yaw and speed of the survey vessel or towfish.

Different frequencies are used. Higher frequencies give improved image resolution but less range while lower frequencies give less resolution but a greater range. The optimal mix of frequencies is chosen for each situation, to give the best results.

The discovery of beamforming

The concept of beamforming was invented by Australian radio astronomer Bernard Mills, who used an array of antennas (two rows of 250 half-dipole elements) that, by adjusting the phasing of the elements, could produce a pencil-like beam which could be steered across the sky.

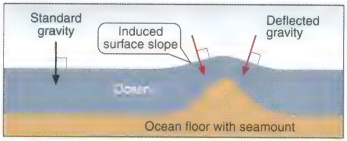


Fig.25: underwater structures cause the sea level to change. This can be measured with satellites. A seamount might be a few kilometres high and produce a bump in the sea level of a few metres, which is in the detectable range.

The telescope was built in 1954 at Badgery's Creek, near Sydney. The Mills Cross beamforming technique (as it became known) was used by American U2 spy planes for radar mapping over the Soviet Union between 1956 and 1960.

After a U2 was shot down in 1960, engineers at General Instrument Corporation, who made the U2 radar, looked for other uses for the technology.

The principles used were just as valid for acoustic energy as for radio energy, so they decided to use it to produce the first multibeam sonar.

This was then adopted by the US Navy and tested in 1963, with a system known as SASS or Sonar Array Sounding System. It operated at 12kHz and had 61 1° beams.

This system was classified (ie, secret) then and even today, some of the bathymetric data produced by it remains classified or is released in a smoothed or lower-resolution format.

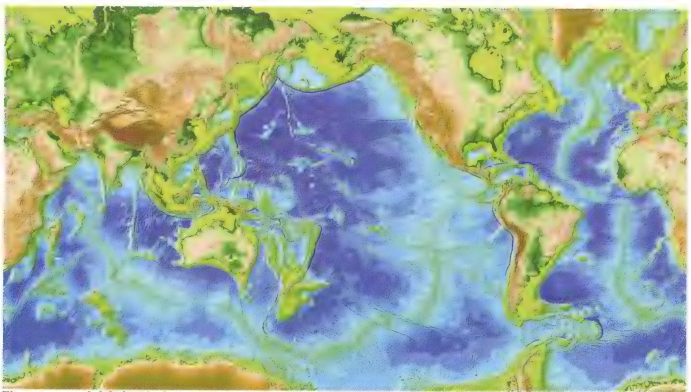


Fig.26: a map of global seabed topography based on both satellite altimetry (gravity-based) and ship-based depth soundings, from the US Government agency NOAA. The gravity data is used where sparse ship-based depth readings are unavailable.

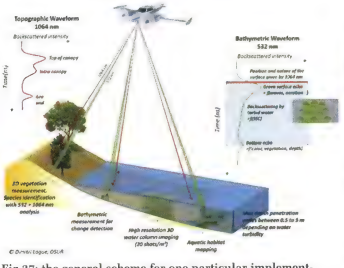


Fig.27: the general scheme for one particular implementation of airborne LIDAR. This image shows its use for both bathymetric and land topographic imaging and the expected return waveforms for the laser pulses. An infrared beam (1064nm) is reflected from the surface of the water while the green beam (532nm) is reflected from the seabed. (Courtesy: Dimitri Lague, Université de Rennes)

Fig.28: the LADS equipment. (Courtesy: RAN)

At about the same time as SASS, a Narrow Beam Echo Sounder (NBES) intended for non-military use was produced which had 16 beams of 2-2/3°.

The NBES technology became what is now known as the SeaBeam Classic, which was the first commercial multibeam sonar system and was installed on Australia's survey vessel HMAS Cook in 1977.

In modern multibeam systems, the transducers can either be attached to the vessel (Fig.19) or be in the form of a towfish or remotely operated vehicle.

Note that while we said that multibeam sonar systems work based on the echo delay rather than strength, it is also possible to determine and process the echo strength to determine how reflective each particular object on the bottom is, giving a more detailed (eg, false coloured) map – see Fig.22.

Most modern multibeam systems can also produce backscattered images as for side scan sonar, but the images produced are not as good as a dedicated side scan system. This is because a multibeam system will produce one backscatter data point per beam, whereas a dedicated side scan system will produce essentially a continuous series of values and therefore the result has a much higher resolution.

It is therefore important to choose the appropriate instrument for the information that is required. Some systems are hybrids and combine side scan imaging systems with multibeam bathymetric systems. (See Fig.23).

Satellite bathymetry

Satellite-derived bathymetry or satellite optical bathymetry uses optical sensors on satellites to detect sunlight reflected from the seabed to determine depth. Mathematical algorithms are used to calculate depth depending upon such factors as the wavelengths of light reflected and the amount of each wavelength, seabed types and reflectance of the seabed (see Fig.24).

These systems typically use specific "registration" points of known depth and properties for calibration. The depth capability of the system depends on the turbidity of the water. In very turbid water, it might be 0-5m, in moderately turbid water it might be 10-25m and in clear waters, it might be 25-35m.

Horizontal accuracy is similar to the resolution of the satellite imaging sensor, which is typically 2-5m, depending on the sensor, and depth accuracy is around 10-20% of the actual depth. A similar technique can also be used from aircraft.

The search for MH370

Australia was extensively involved in the search for missing Malaysian Airlines flight MH370, and this was discussed in the Silicon Chip article of September 2015 on Autonomous Underwater Vehicles (AUVs) - see **siliconchip.com.au/Article/9002**

The search involved the acquisition of high-resolution side scan and multibeam sonar images of remote parts of the southern Indian Ocean which had never before been imaged. The search was in two phases.

Phase 1 used multibeam sonar mounted on a vessel to map the ocean floor, since only low-resolution satellite gravity measurements were available.

Phase 2 involved lowering a "towfish" from the search vessel thousands of metres, to within 100m of the seabed, where it produced photograph-like side scan and multibeam sonar images up to 1km on either side.

The search was one of the largest marine surveys ever and involved the collection of 278,000km^2 of bathymetric data and 710,000km^2 of data overall.

The data was released to the public on 28th June 2018. The imagery revealed unknown shipwrecks, whale bones and geological features.

Although the remains of MH370 were never found, the extensive data set is of scientific value and of general interest, so there was at least some return on the many millions of dollars spent on the search, even though the aircraft was unfortunately not found.

A very interesting interactive "story map" showing the data and features of interest has been placed on the web at **siliconchip.com.au/link/aany**

You can download Phase 1 data from **siliconchip.com.au/link/aanz** and Phase 2 data from **siliconchip.com.au/link/aaoo**

Fig.29: the aircraft used to carry LADS, a de Havilland Dash 8-202. (Courtesy: RAN)

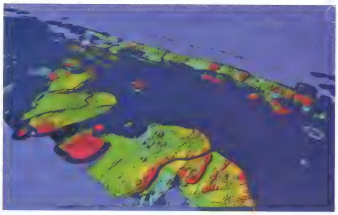


Fig.30: typical LADS survey data. (Courtesy: RAN)

Another form of satellite bathymetry, satellite radar altimetry, relies on the fact that structures beneath the ocean alter the gravitational pull over that area and cause changes in the ocean surface level, which can be measured by satellites using radar.

This results in a low-resolution map of an area showing general features such as underwater mountains and mountain ranges. See Figs. 25 & 26.

Laser Airborne Depth Sounder (LADS) and LIDAR

Lasers can be used from aircraft to determine seabed depth and such systems are generally known as LIDAR (LIght Detection And Ranging) – see Fig.27. Australia was a pioneer in developing this technology and has a system known as LADS (see Figs.28-30).

Australia has a vast ocean area within its territorial waters and a huge area of search and rescue responsibility (53 million km^2, or 10% of the earth's surface) and many of these waters (such as reef areas) are hard to map due to their relative inaccessibility and lack of existing charts.

Some of the charts used until recent times (the 1970s) were actually made by Captain Cook!

There was therefore an urgent need to develop a system that could remotely measure ocean depths, and this was produced by the then Defence Science and Technology Organisation (DSTO) which started feasibility trials of the LADS system in 1977.

An aircraft flies over an area of interest and an onboard laser system emits two beams (originating from a single laser), one of which is reflected off the ocean surface and the other is reflected from the seabed. The relative distances from the aircraft are computed and the depth of the seabed below the sea surface can therefore be determined.

The laser used is a Neodymium:Yttrium-Aluminum-Garnet (Nd:YAG) laser which typically emits in the infrared. The beam also goes through a frequency doubler to produce a green beam. The infrared beam is reflected off the ocean surface and the green beam is reflected from the seabed. The beam has a pulse repetition rate of 990Hz.

The system can measure depths of 0-80m and measure surface topography (land) from 0-50m in height. The aircraft flies at an altitude of 1200-3000 feet (360-915m) at a speed of 140-200 knots (260-370km/h). The beam (swath) width is 114-598m; for standard surveys, it is 193m. Data points are between 2-6m apart across the beam.

The aircraft can go on sorties of up to seven hours, which it does about 140 times per year. Note that this system is suitable only for relatively shallow waters (ie, up to 80m deep); other sounding systems are used elsewhere.

The Royal Australian Navy, in conjunction with Fugro LADS Corporation and other subcontractors, operates the LADS system from Cairns airport and the data that is collected is sent to the Australian Hydrographic Office in Wollongong for processing.

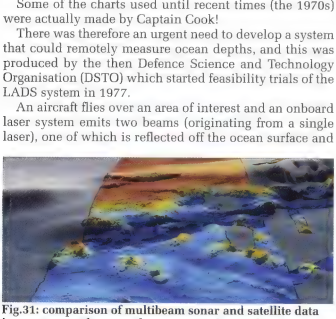


Fig.31: comparison of multibeam sonar and satellite data imagery around an area known as Broken Ridge showing new multibeam sonar mapping data in colour, compared with older, much lower satellite resolution data in monochrome. (Source: Geoscience Australia)

Mapping under the seabed

In our article on A Home-Grown Aussie Supercomputer in the November 2018 issue, we described how Downunder Geosystems uses their supercomputers to process the data from huge arrays of hydrophones – up to 10,000 in a single survey (siliconchip.com.au/Article/11300).

Unlike the sonar systems described above, they do not use transducers to produce sound waves. Because they are mapping the area under the seabed, they need powerful soundwaves to penetrate the rock strata.

So a large underwater air cannon is used to generate the initial sound waves.

Some of these pass through the seabed and reflect off layers below, including oil and gas deposits, and are reflected up to the surface where they are picked up by the towed hydrophone arrays and recorded for later processing.

The vast amount of data and complex reflections mean that it takes days of processing by a huge supercomputer to turn the resulting data into a 3D map of the area under the seabed. This is ideal for determining where to drill for oil and gas. SC

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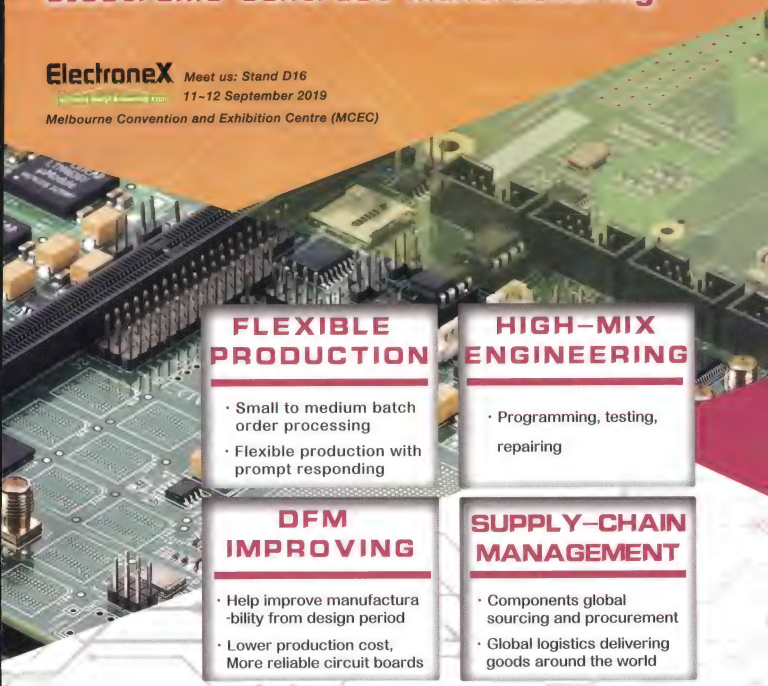

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This low-cost, easy-to-build and user-friendly RF signal generator covers from 100kHz–50MHz and 70–120MHz, and is usable up to 150MHz. It generates CW (unmodulated), AM and FM signals suitable for a wide range of tests. Its output level is adjustable anywhere between -93dBm and +7dBm and it has an accurate frequency display. It also includes a scanning function for filter alignment.

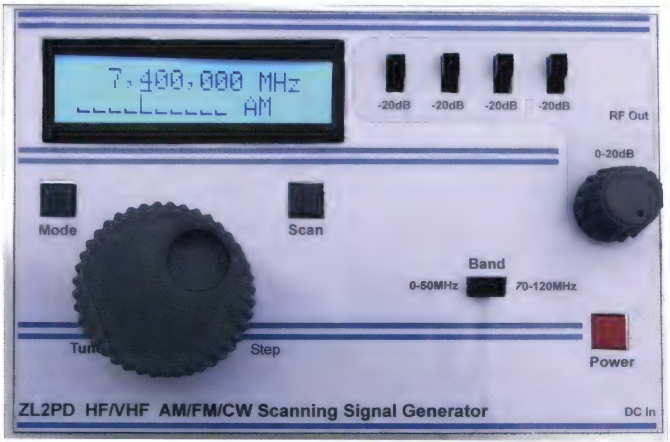
I've always wanted a *good* AM/FM HF/VHF signal generator. I have tried to meet that need with a variety of designs over the years, some analog, others using DDS chips.

More recently, I have tried low-cost fractional-N oscillator chips, including the Si5351A. These were only suitable in specific circumstances, and did not make for a good general-purpose test instrument.

Obviously, it's possible to purchase an RF signal generator, new or used, but I couldn't afford the price of a good one. Cheap signal generators lack adequate performance and useful functions. Those with adequate performance are usually too expensive for most hobbyists or are unreliable and difficult and/or expensive to maintain.

I have seen some designs published, but these are typically simple analog LC-based designs with coverage up to around 150MHz, in a series of five or six switch-selected bands.

Most lack accurate frequency read-outs or adequate stability. Spurious



canning HF/VHF tor

Part 1

by Andrew Woodfield, ZL2PD

and harmonic outputs can also be a problem.

(See the list of references at the end of this article for three such designs that I considered and rejected).

Table 1 (overleaf) shows what is available at the moment. I rejected all of these options for one reason or another – inadequate performance, lack of features, high price or unreliability.

With few exceptions, the output levels of most of these generators are quite limited. Those with a variable output level typically use a simple potentiometer, with little regard to varying output impedance or accuracy.

Output levels are also often too low for use in many typical applications.

Modulation, where available, is often limited. And, finally, some otherwise useful digital-based designs are now difficult or impossible to build due to obsolete parts or unavailable software or PCB layouts.

Basic analog and digital PLL-based RF signal generators are available between about $200 and $300. The analog generators offer basic CW, AM or FM modulation. Output level and modulation depth on the low-cost analog generators are typically controlled via internally mounted trimpots adjusted through small holes in the panel.

The low-cost digital signal generators only offer FM and appear aimed at the two-way radio industry.

These instruments are all perfectly functional, but for hobbyists, these features are too limited. To use them effectively, you would also need extra equipment such as a frequency counter, attenuators, amplifiers and a level meter. It's far easier to have these features built into the generator.

As Table 1 shows, moving up in the market significantly increases the price. Used equipment is available at lower cost, but many otherwise excellent instruments have recognised spare parts or reliability issues as the equipment ages.

So I needed to come up with my own design that would tick all the boxes, and that is just what I have done. See the table below which lists its features and performance figures.

Features and specifications

	Specification	Comments
Coverage	100kHz-50MHz, 70MHz-120MHz	Usable up to 150MHz
Tuning Steps	10Hz to 1MHz in decade increments	User-selected
Accuracy & stability	Within 150Hz at 30MHz (typical), 0-40°C, 0-80% humidity	Can be enhanced with software calibration
Output level	-93dBm to +7dBm (approximate)	50Ω termination
Attenuation steps	0-80dB in 20dB steps (switched) + 0-20dB (variable)	
Output socket	SMA	
Spurious and harmonics	Typically better than -30dBc	Within specified coverage frequency range
AM	30% modulation @ 1kHz	
FM	NB (12.5kHz spacing), 1.75kHz deviation @ 1kHz (60%)	
	WB (25kHz spacing), 3kHz deviation @ 1kHz (60%)	
	BC (12.5kHz spacing), 50kHz deviation @ 1kHz (60%)	Suitable for standard broadcast FM receivers
Scanning	Programmable start and stop frequencies	1kHz resolution
	10, 20, 50, 100, 200 or 500 steps/sweep	Auto step size calculation
Display	16x2 alphanumeric LCD	
Power control	Soft on/off switch	
Controls	Two knobs and eight switches	
Power supply	9-12VDC at 250mA	
Dimensions	160 x 110 x 25mm (excluding knobs)	
	160 x 110 x 45mm (including knobs)	
Weight	~250g	

PRODUCT	TYPE	PRICE BAND ($US)	FREQUENCY COVERAGE	OUTPUT	MODULATION	FEATURES
Generic brands	Analog	$150–$200	100kHz–150MHz in six bands	0–100mVpp	Basic AM, FM	Analog dial, internal presets for user controls
Generic brands	Digital PLL?	$150–$200	500kHz–470MHz	–132 to –70dBm	CW, FM	2 line x 16 char LCD display
RF Explorer	PLL and dividers	$200–$300	24MHz–6GHz	–40 to 0dBm	None	Sweep functionality
ERAsynth	PLL, controlled by user PC or smart device	$950	250kHz–6GHz	–60 to +15dBm	AM, FM, pulse via external apps	Software apps control functionality
Digimess SG200	Digital	$2500	9kHz–450MHz	–127 to +13dBm	AM, FM, FSK, PSK	Sweep functionality
Used signal generators, eg Marconi 2022, HP8640	Digital/PLL	$500–$1000	10kHz–1000MHz	–127 to +13dBm	AM, FM, FSK, PSK	Excellent performance, but some models have recognised maintenance issues
Keysight, R&S, Tektronix, IFR, TTi, Rigol, Gratten, etc.	Digital	$3000–$20,000+	10kHz–15GHz (depends on model)	–140 to +20dBm, typically	All (AM, FM, PM, FSK, QPSK, etc.)	Extensive array of features and functionality

Table 1: I looked at a range of currently available commercial equipment, both new and used. However, for anything that had better-than-mediocre performance, that third column definitely caused me some heartache! I estimate the instrument described here could be built for not much more than $75.00, plus case.

Design goals

This design represents the outcome of an extended period of development and testing over the last few years.

This signal generator provides basic CW (unmodulated) signals, plus AM and FM modulation functions, primarily across the high frequency range from 100kHz to 30MHz, with a continuously variable output level suitable for most requirements.

This frequency range includes most common IFs (intermediate frequencies) such as 455kHz, 465kHz, 470kHz, 10.7MHz and 21.4MHz.

Coverage extends to 50MHz, with another range covering 70-120MHz. Coverage actually extends up to 150MHz with some limitations, to permit limited use in the popular 2m amateur radio band as well as parts of the widely used international 138-174MHz land mobile band.

Key design objectives included low cost, ease of obtaining parts and ease of construction.

Special parts such as chip-based attenuators, for example, were avoided in favour of the low-cost combination of slide switches and standard resistors.

The generator's RF output is designed for applications requiring relatively high RF levels.

These include testing double-balanced diode mixers in high-performance receivers and for testing multi-stage passive filters, where stopband attenuation measurements require relatively high signal generator outputs.

Lower RF output levels are also useful, eg, for receiver sensitivity tests. The minimal useful level is mostly determined by the limitations of low-cost shielding and simple hobbyist construction methods used.

If an enclosure was carefully milled from a 25mm thick metal billet with shielding slots for flexible conductive inserts, the lower limit could be extended significantly, but relatively few hobbyists could achieve this. So I've used simple shielding and a basic DIY folded aluminium sheet metal box. This is reflected in the modest lower output specification limit of around -90dBm.

Achieving that performance, however, still requires moderately careful enclosure construction.

By using commonly available parts and low-cost modules, I have been able to keep the overall cost low. I estimate the cost to build this signal generator currently at around $75.

Design approach

As shown in Fig.1, a modern signal generator consists of five functional blocks: the RF oscillator, the modulator, RF buffer amplifier, a variable attenuator to control the output level, and some control electronics. The logical implementation of the control electronics is based on a microcontroller. The final block is the power supply, either battery-powered or mains-powered (or both).

The oscillator is a key element of any signal generator. An analog-based wide-range oscillator and modulator involving sets of inductors and a tuning capacitor is impractical and cannot provide the desired functions and performance required at a modest cost.

The cheapest digital options include the powerful Silicon Labs Si5351A device or widely available direct digital synthesis (DDS) modules based on chips such as the Analog Devices AD985x (see our article on the AD9850 in the September 2017 issue; siliconchip.com.au/Article/10805).

Other digital options include PLL chips such as the Maxim MAX2870. While it is possible to generate sinewaves from both the Si5351A and the MAX2870, the additional circuitry required to obtain low harmonic content output signals coupled with the challenges of adding modulation make them less attractive.

AD9850 DDS modules (as shown in the photos overleaf) are available from sources like ebay and AliExpress at reasonable prices.

The instrument's display requirements are modest, so I decided to use a common 16x2 character alphanumeric LCD. These are easy to read and drive from a micro.

A rough outline of the design began to take shape and, adding up processor pins required, the very common

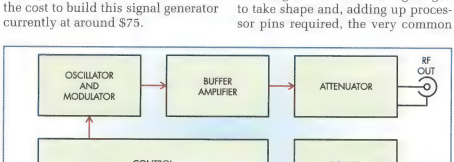


Fig.1: the basic arrangement of a modulated signal generator with adjustable output level. Our design follows this configuration.

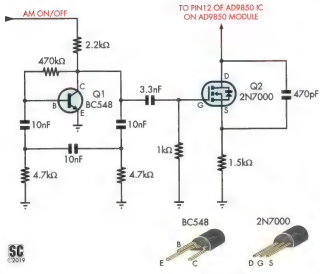


Fig.2: a typical example of how you can apply amplitude modulation to the output of an AD9850-based signal generator module using discrete components. In the end it was decided to abandon this idea in favour of a PWM-based microcontroller approach.

ATmega328P 8-bit microcontroller appeared suitable. While an Arduino was briefly considered, I would need to use practically every pin on the device, and I wanted to keep the instrument compact, so I decided to use a stand-alone ATmega328 processor.

The RF buffer amplifier requires only modest gain. It must handle the somewhat unusual 200Ω output impedance of the AD9850 module and the following 50Ω attenuator stages and 50Ω output. Another consideration is that the buffer should not be overloaded by the sometimes high output swing of the AD9850. Numerous designs published on the internet suffer from this problem.

The buffer should also maintain its gain across the design frequency range. And the buffer should be able to work into a reasonable range of loads and survive typical bench treatment.

I've used MMIC amplifiers such as the ERA-series devices from Mini-Circuits to buffer AD9850, AD9851 and AD9854 DDS chips in the past. These drive 50Ω loads with good performance.

However, in testing this signal generator with a wide variety of filters, amplifiers, receivers, transmitters and other loads, several MMICs suffered early deaths. These were probably due to the very low impedances presented by some of the test filters.

The search for a more suitable buffer stage was ultimately concluded with the inclusion of a traditional single-stage buffer amplifier using a robust 2N4427 VHF transistor. It is widely available at low cost, as is its near-equivalent, the 2N3866. It proved more than adequately robust over many months of use. The TO-39 case of the transistor becomes warm during use, but a heatsink is not required.

The design of the attenuator stage also posed some challenges. Recently, PE4302 30dB step attenuator chips have become popular. While only relatively new devices, these have recently been listed by the manufacturer as obsolete. The replacement devices, while having improved performance, also come at a substantially increased price.

Relay-controlled fixed attenuators can be used, but with an eye on cost and simplicity, I decided to use inexpensive slide switches instead. Experience has shown these to perform adequately for this type of application. However, these limit the attenuator steps to specific attenuation values. Ideally, the generator should have a fully variable output level.

So I decided to build and test a Serebriakova attenuator as an alternative to a more costly PIN diode-based design. This configuration is shown in the lower right-hand corner of Fig.4, the circuit diagram.

It's a simple passive resistor network which acts as a variable attenuator, well suited for basic designs like this. Apparently of Russian origin, the attenuator network uses a 500Ω linear potentiometer to give a 20dB variable attenuation range. It works well into mid-VHF frequencies.

The input impedance is maintained reasonably close to the desired 50Ω across the adjustment range of the potentiometer, so the attenuation is predictable. The output match to 50Ω as the potentiometer is adjusted

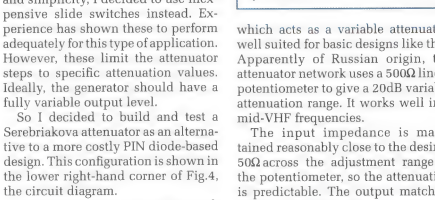


Fig.3: the output of a DDS signal generator module contains the wanted frequency plus a number of alias frequencies. These are normally filtered out but it is possible to instead filter out the fundamental frequencies and keep one of the higher alias frequencies to extend the signal generator's range.

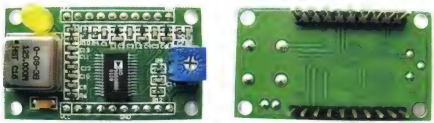
What is Frequency Modulation (FM)?

With frequency modulation, the audible tone of (say) 1kHz results from the carrier frequency of the signal generator being instantaneously shifted (or "deviated") from its nominal frequency in proportion to the amplitude of the modulating tone.

As the amplitude of the tone increases, at that 1kHz rate, the carrier frequency of the generator proportionally increases. Similarly, as the 1kHz tone's amplitude decreases, the carrier frequency is proportionally decreased. It is proportional because the extent of the carrier frequency shift, or deviation, depends on the signal bandwidth required.

For broadcast radio FM, the peak deviation is ±75kHz. The resulting signal fills the standard FM broadcast channel bandwidth of 200kHz. Traditional VHF FM two-way radio transceivers used for amateur radio or commercial/government mobile radio use a much smaller ±5kHz deviation, and these signals occupy 25kHz channels.

More modern so-called "narrow-band" amateur FM transceivers typically use ±2.5kHz deviation, and these use more densely-packed channels spaced apart by 12.5kHz.



This is the low-cost AD9850-based DDS signal generator used in this design. Besides the chip it has a reference osciallator (the metal can at left) plus a number of discrete components including a low-pass filter for the output.

is not perfect, but it's an acceptable compromise for this design.

Amplitude modulation with the AD9850

A key objective of the signal generator was to deliver both amplitude (AM) and frequency modulation (FM) as well as providing an unmodulated RF signal.

Amplitude modulation with the AD9850 is well documented. Analog Devices, the chip's manufacturer, helpfully published an application note (AN-423) which describes adding a small signal NMOS FET and a few additional parts to do this. A quick test confirmed that it works as described.

Most signal generators use a 1kHz modulation tone, which can be produced in several ways. One approach is to use the ATmega328 to generate a 1kHz square wave using one of its internal timers and then filter this to give a 1kHz sinewave. But extensive filtering is required to obtain a suitable tone. That involves quite a few extra parts.

A second, similar approach is to use the ATmega328's counter/timer in its pulse-width modulated (PWM) mode. The resulting waveform is closer to a sinewave but still requires some filtering to remove the 31kHz PWM frequency. Usefully, that filter is far less complex given the much higher clock frequency compared to the 1kHz tone.

A third option is to build a discrete 1kHz sinewave oscillator and just use the ATmega328 to turn it on and off as required. At first glance, the discrete oscillator approach is attractively simple and uses relatively few components, so I tested this out, using the circuit shown in Fig.2.

It works quite well. The 3.3nF capacitor value can be adjusted to give the required modulation level at the AD9850's RF output. This works by replacing the fixed resistor ("RSET") on pin 12 of the AD9850, typically 3.9kΩ, with the variable resistance of Q2's channel. This resistance sets the AD9850 digital-to-analog converter (DAC) current and, subsequently, the AD9850 RF output level.

By varying the gate voltage of the 2N7000 at 1kHz using the voltage from the collector of audio oscillator Q1, the AD9850 RF output is amplitude modulated.

However, this analog tone is not precisely 1kHz. Its frequency is determined by the passive components around Q1. To give a more accurate (and potentially adjustable) modulation frequency, the PWM-based approach was used in the final circuit. See the section of Fig.4 labelled "OUTPUT LEVEL CONTROL".

Pin 11 (output PD5) of IC1 produces the 1kHz sinewave as a 31kHz PWM square wave, or potentially at other frequencies by changing the software. This is filtered and used to control a current sink made using standard NPN transistors. An extra 100nF bypass capacitor was added to pin 12 to the final PCB to address AD9850 module stability.

The 31kHz pulse width modulated 1kHz signal is produced by the ATmega328 from its 8MHz internal RC oscillator. The variable DC voltage of 0-5V arriving on the base of Q1 is converted to a variable collector current in Q1 of 0-700μA, the maximum current value being set by its 1kΩ emitter resistor. This figure was selected to exceed the 625μA maximum current sink range required by the AD9850.

This approach is not perfect. Using the RSET pin and the standard unbalanced RF output from the AD9850 module, the typical approach used in these low-cost modules, the output modulation produced is asymmetric. In practice, however, this does not matter terribly.

This simple circuit delivers clean-sounding amplitude modulation with the AD9850 and uses fewer components than the other options. It also allows other modulation tones to be added in future if required. Finally, this approach also adds another important feature – reasonably accurate linear control of the AD9850 RF output level.

Note though that this approach requires the removal of that 3.9kΩ resistor from the module as supplied, and the addition of a wire to control pin 12 from Q1 to one of its pads. This change will be described in more detail later.

Frequency modulation (FM)

Again, there are several options to produce FM with the AD9850. One approach would be to externally modulate the AD9850's separate 125MHz reference crystal oscillator. Frequency and phase modulation could be both implemented this way. Unfortunately, the 125MHz reference oscillator in the low-cost modules is inside a sealed metal can.

There is no external voltage tuning input which might otherwise be pressed into use to produce FM. It's possible to replace the reference oscillator module with a discrete oscillator to allow for external modulation, but that takes some effort.

It is also possible to use the AD9850 internal phase modulation register but resolution is too limited (4 bits).

Another Analog Devices application note (AN-543) suggests a solution. It describes a powerful Analog Devices DSP chip which samples incoming stereo audio at 48ksamples/sec and then sends a stream of 40-bit frequency-setting words serially at very high speed to the AD9850.

Each of these 40-bit words programs the AD9850 to a new instantaneous frequency, which is necessary to emulate a stereo FM signal (including the 19kHz and 38kHz pilot tones).

With some care and a few lines of assembly code for speed where necessary, the ATmega328 can modulate the AD9850's output frequency in this manner. Sadly, the resulting modulation sounds pretty average. The problem is the time required by the ATmega328 to send the serial string of 40 bits to the AD9850 each time its frequency has to be updated for frequency modulation via the typical 3-wire interface.

The poor result is not surprising. With the conventional serial load

method and our 8MHz, 8-bit chip, it is (just!) possible to load four modulation samples per 1kHz cycle into the AD9850. A four-point sinewave is actually a triangle wave, which is full of harmonics!

Closer study showed that there is another way to communicate with the AD9850 chip. Almost every AD9850/51 based design uses the three-wire serial bus to send 40-bit control words to the AD9850 each time the frequency needs to be updated.

However, the AD9850 can also be controlled using a parallel interface. This requires sending five 8-bit words in quick succession to the chip, along with some control signals via two or three additional pins. The only published example I could find is based on a PIC processor.

There is a considerable advantage in this method. Rather than taking about 250µs for the ATmega328 to load each 40-bit word serially, the parallel approach can reduce this to as little as 2.5µs.

With the parallel loading method, it is possible to send 20 samples per 1kHz cycle without any trouble at all, even with the (relatively) slow 8MHz clock in the ATmega328. This is much closer to a proper sinewave. The difference is clearly audible in an FM receiver. The parallel method gives a demodulated signal that sounds very clear and clean, just like a sinewave should.

So for FM, the 20-point sampled waveform is created by calculating the required AD9850 output frequency every 50µs and sending that data over the fast parallel interface.

The FM deviation is controlled by changing the magnitude of the frequency changes which occur 20,000 times per second (20 points x 1kHz).

Selecting narrow band FM (the LCD shows "FM-NB") on this generator for 12.5kHz spacing FM two-way radios produces ±1.5kHz FM; selecting wideband FM, for older 25kHz channel spaced two-way radios, gives ±3kHz FM ("FM-WB"), while selecting broadcast FM produces ±50kHz FM signals ("FM-BC").

Frequency scanning

A further feature of this signal generator was added for testing and aligning filters. For example, while designing this Signal Generator, I was also building a 9-band HF transceiver. Its receiver front end features nine sets of coupled tuned circuits, each requiring careful alignment, with three or four adjustments per set.

In the scanning mode, the generator briefly produces a signal on a series of discrete frequency steps across a defined range. For the transceiver example, the signal generator could be programmed to produce signals across each of the nine bands used for the bandpass filters being tested.

By monitoring the amplitude of the resulting output from each filter on an oscilloscope, it is possible to quickly align each filter while seeing the impact of every change. This forms, in effect, a 'poor man's spectrum analyser'. This saves considerable time and effort over manual alignment methods.

The start and stop frequencies can be set anywhere across the range of the signal generator. Since filters are generally fairly broad, a 1kHz step size for setting the start and stop frequency is acceptable.

I decided to add a SCAN pushbutton to the design, to enable this mode. As I had run out of pins on the ATmega328, I used two diodes (D1 & D2) so that pressing this button is effectively equivalent to pressing the two existing buttons (MODE and STEP) simultaneously. The micro can detect this as a press of the SCAN button – see Fig.4.

Expanded frequency coverage

Typical AD9850 modules are fitted with a 125MHz reference oscillator. DDS oscillators deliver clean sine outputs up to about 30% of the reference frequency; in this case, say 40MHz. Increasing but acceptable levels of aliasing products are present in the output spectrum up to 45% of the reference frequency, say 50MHz.

Beyond this, as the output frequency approaches the Fourier limit of about 60MHz, spurious products render the output unusable.

The cheap modules are usually supplied with an onboard elliptical low-pass filter with a cutoff frequency of 70MHz to maximise the output frequency range. In fact, these modules have three outputs. The first is the filtered output as described. It appears on my module on the pin labelled "SINB".

An adjacent pin, "SINA", might appear to be similar. However, this signal comes directly from the AD9850 DAC. It is a 180° phase-shifted (inverted) version of the signal at SINB but without any additional low-pass filtering.

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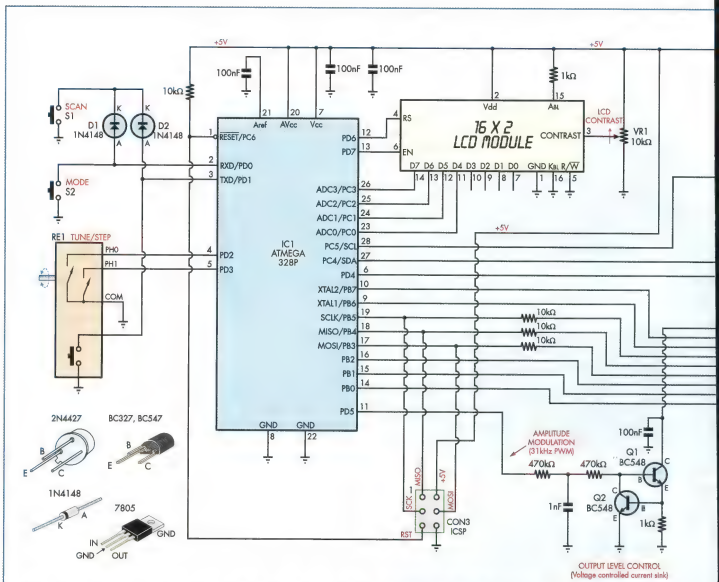
The third available output comes from an internal comparator in the AD9850. It produces a square wave version of the output. This is output level dependent, the duty cycle being set by adjusting a miniature trimpot on the module. If it is adjusted for a good 50% duty cycle output at a lower frequency setting, it tends to be less accurate at higher frequencies.

There is little difficulty in obtaining reasonably clean filtered signal generator outputs up to 50MHz from the filtered (SINB) pin. Some testing showed that output was acceptable down to 100kHz. That's useful for covering receiver intermediate frequencies (IF) and IF filters between 455kHz and 470kHz, for example.

Looking more closely at the module, the second SINA output looked potentially useful too. Because this output is not filtered, the full set of DDS alias frequencies are available here.

In one example, illustrated in Fig.3, the "wanted" output (labelled Fout) is at 30MHz. As the user increases this frequency, tuning towards 35MHz for example, this output frequency increases, shown by the blue arrow.

At the same time, the AD9850 (like



AD9850-BASED CW/AM/FM HF/VHF SIGNAL GENERATOR

Fig.4: along with the 16x2 LCD module, the ATmega328P microcontroller (IC1) drives the AD9850 signal generator module using an 8-bit parallel bus plus three control lines. This allows it to modulate the output frequency at 20kHz which results in clean 1kHz frequency modulation. Amplitude modulation is applied using PWM from pin 11 of IC1, which is filtered and then controls a current sink comprising transistors Q1 and Q2. The resulting current flow controls the signal generator output level. The output signal is buffered by transistor Q3 and then passes four switched 20dB attenuators and then a 0-20dB variable attenuator (VR2) which gives a 100dB overall output range. Q4 and Q5 form a "soft power" switch for the circuit, which is controlled by pushbutton switch S3.

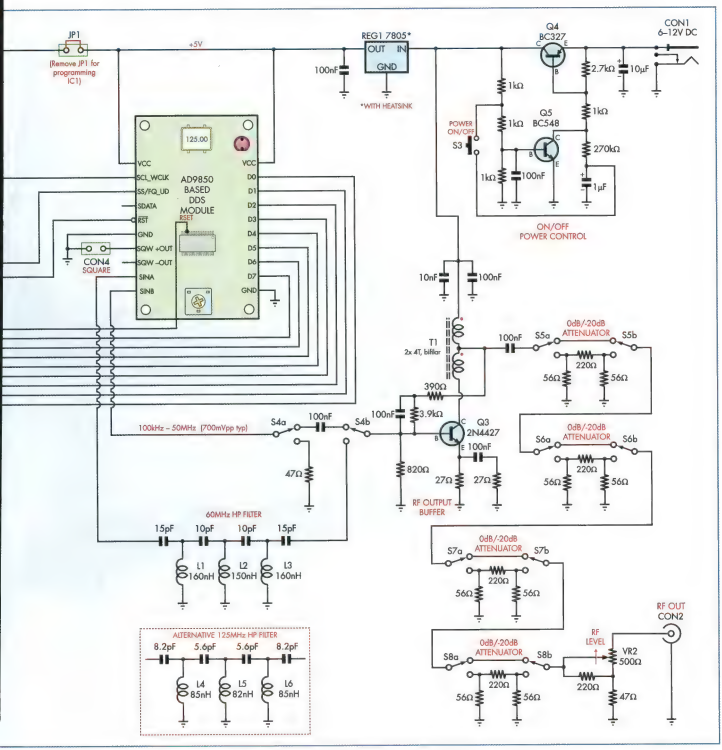
all DDS chips) also produces "alias" frequencies. These are shown in orange. The nearest is at 95MHz, ie, the clock frequency of the DDS (125MHz) minus 30MHz. It decreases in frequency as the user tunes from 30 to 35MHz, ending up at 90MHz (ie, 125-35MHz).

There are many other alias frequencies which are produced simultaneously, the next nearest being at 155MHz (the clock frequency of 125MHz plus 30MHz), with others at 220MHz, 280MHz and so on, theoretically continuing forever. The direction these alias outputs tune can be seen by the direction of the arrows, some rising while others reduce in frequency as the primary frequency is increased.

The amplitude of all of these signals follows a strict mathematical relationship, called the "sine x upon x" curve. That's shown in green on the figure. There's about a 10dB level difference between the 30MHz output and the 95MHz alias signal, for example.

That's the reason for the substantial onboard filter on the AD9850 module. It's a low-pass filter designed to cut off at 70MHz, so the majority of these aliased products do not appear at the SINB output. However, since there is no similar low pass filter on the SINA output, these alias signals are all usefully present, in full, at this pin.

As the user continues to tune the AD9850's output upwards in fre-



quency, the 'wanted' and first 'alias' output ultimately coincide and pass each other at Fout=62.5MHz.

A few tests using this SINA pin suggested that the usually unwanted alias frequencies above 65MHz could be obtained from the module using an external high-pass filter (HPF). That would allow the signal generator to provide useful outputs from, say, about 70MHz up to about 120MHz. With additional filtering, still higher aliasing products could be filtered out and amplified.

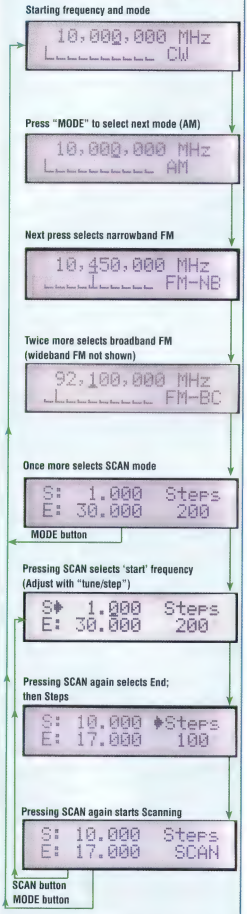
This permits the generator to produce signals across the 2m amateur band or across part of the 138-174MHz land mobile bands. As it turns out, useful outputs across these bands could be obtained just from using a single HPF, and the maximum tuning frequency for the signal generator was therefore set at 150MHz. Those wanting other bands or fewer aliasing outputs can modify the HPF to suit individual requirements.

Detailed circuit description

The final circuit arrangement is shown in Fig.4.

While it may appear complex at first glance, this design uses remarkably few components given the range of modulation modes and coverage it provides. Some of the complexity is hidden in the software for IC1.

NAVIGATING THE MENUS



To enable the frequency modulation described above, the AD9850's 8-bit data port (pins D0-D7) is connected to micro IC1's PORTB digital outputs (PB0-PB7). The three 10kΩ series resistors have been added so that IC1 can be reprogrammed in-circuit (via ICSP header CON3) while IC1 is still connected to MOD1.

MOD1 is also connected to 5V power (VCC) and GND, plus the slave select (SS) and reset ($\overline{RST}$) pins, which go to digital I/Os PC4 and PD4 on IC1 respectively.

Its two output signals are fed to the HPF and switch S4, while the square wave output goes to CON4, although the signal which appears there is of limited use, as its duty cycle varies with frequency.

With switch S4 in the position shown, the lower frequency (100kHz-50MHz) signals pass through S4a, the 100nF coupling capacitor and S4b directly on to the buffer amplifier (the base of transistor Q3).

For higher frequency signals, S4 is moved to the alternative position where the buffer amplifier is fed from the output of the HPF, which receives its input from the unfiltered DDS output pin.

The HPF is a standard seven-pole Chebyshev filter. Elliptical filters provide a faster pass-to-stop band cut-off, but the resulting spurious and harmonic rejection is less effective compared with the Chebyshev type.

The filter was optimised to suit standard leaded components and home-made inductors.

For best performance, the coupling between the coils must be minimised. The PCB layout provides for small tin plate shields to be fitted between filter stages, a simple and effective solution.

The alternative HPF shown could potentially shift the 70-150MHz upper output range to 125-187.5MHz with appropriate software changes.

RF buffer amplifier

As noted earlier, the buffer amplifier is a robust discrete design, based on NPN transistor Q3. This is a well-known single transistor broadband arrangement providing about 15dB gain along with good dynamic range. Gain is necessary to provide the required maximum output level for the signal generator and to compensate for the insertion loss of the Serebriakova attenuator.

Alternative discrete buffers seen in other AD9850/51 based designs lack sufficient gain across the output range and/or frequently overload with the typically higher module output levels present below 10MHz.

By contrast, this buffer amplifier's gain is relatively flat and only reduces above 50MHz. This is acceptable given the application and circuit simplicity.

If you find the 2N4427 transistor difficult to source, you may be able to find a 2N3866 instead, although the gain may reduce by several decibels.

The output of the amplifier is taken from the centre tap of autotransformer T1 and coupled to the output attenuator by a 100nF capacitor.

The attenuator consists of four identical 0/20dB switched attenuators, followed by the aforementioned 0-20dB Serebriakova attenuator, giving an overall range of 0-100dB. This allows you to adjust the output from about -93dBm to +7dBm.

As mentioned earlier, this range is limited by shielding effectiveness and RF signal leakage across the attenuator sections.

Better shielding between sections is likely to allow another 20dB fixed attenuator to be added, significantly improving its utility for small signal work. Further improvements would likely require considerable additional design efforts around the power supply and control sections.

User interface

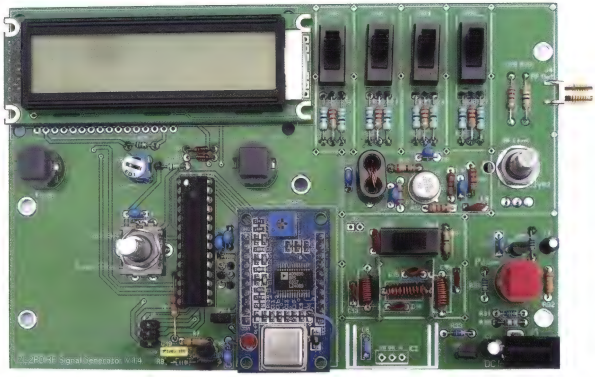
IC1 updates the 16x2 LCD using a typical 4-bit interface. The lower four bits of PORTC on IC1 (pins 23-26) drive the four upper LCD data pins, while pins 12 and 13 (digital outputs PD6 & PD7) drive the RS and EN control lines of the LCD.

The backlight brightness is fixed using a 1kΩ resistor, with the backlight powered whenever the device is on, and trimpot VR1 provides contrast adjustment.

The Grey code pulses from the rotary encoder are sensed using IC1's PD2 and PD3 digital inputs (pins 4 & 5), while presses of the encoder's integral pushbutton and the SCAN and MODE pushbuttons (S1 & S2) are sensed using digital inputs PD0 and PD1 (pins 2 and 3).

These have internal pull-ups enabled so that they are held high when no buttons are being pressed.

As mentioned earlier, diodes D1 and



To whet you appetites for part 2, the construction details (scheduled for our July issue) here is the author's completed prototype PCB. As you can see, despite its complexity and performance, there really isn't all that much to building it!

D2 have been added to allow presses of three buttons to be sensed using the two available pins.

Jumper JP1 and ICSP header CON3 have been provided to allow IC1 to be re-programmed in situ. Removing JP1 prevents the programmer from trying to power the RF circuitry. CON3 has the standard Atmel 6-pin programmer pinout.

Power switching

The external power supply, nominally 12V DC, directly powers the output buffer. The buffer can operate down to 9V although harmonic distortion at full output increases by about 6dB at 9V compared to 12V.

The 12V supply is also regulated down to 5V by REG1 for the AD9850 module and the ATmega328 processor. Since the AD9850 module is current-hungry, REG1 requires a heatsink.

Dissipation losses would be reduced by using a switchmode regulator but this can introduce switching noise inside the signal generator, and could potentially modulate the output buffer output signal.

As it turns out, the metal signal generator case forms an effective heatsink for REG1, and this avoids the need for additional hardware.

The signal generator will continue to operate with a supply voltage down to 6V; however, its performance degrades significantly below 9V. By 6V, the maximum output falls by 10dB and harmonics are only suppressed by 10dB due to the reduced dynamic range in the buffer stage.

So, operation at 6V is possible but not recommended.

A 'soft switch' circuit has been added to allow the use of a momentary pushbutton (S3) as a power switch.

The circuitry to provide this function is shown at the upper right of Fig.4. It was initially described by Zetex in their February 1996 Design Note 27, for use as a relay driver.

However, several problems were encountered with that design, including some curious component choices and overheating. A minor redesign and the use of a higher-gain switching transistor solved them all.

When the supply is initially connected, the voltage appears on the emitter of Q4 and the 1µF capacitor charges via the three series resistors (2.7kΩ, 1kΩ and 270kΩ). However, Q4 cannot turn on until momentary switch S3 is pressed and no current is drawn from the supply.

When S3 is pressed, current is supplied to the base of Q5, which switches it on, and it in turn sinks current from the base of PNP transistor Q4, switching it on also and bringing up its collector voltage.

Current can then flow from Q4's collector to Q5's base via the two 1kΩ series resistors, so Q5 remains on and so does Q4.

However, the 1µF capacitor discharges because Q5's collector is now being pulled low, to 0V. So if S3 is pressed again, Q5's base goes low, switching it off, and in turn switching off Q4, so the circuit is back in the initial off-state.

Part Two, next month

Next month's article will have the parts list, details of PCB assembly, case construction, programming IC1 and how to use the RF Signal Generator. We'll also have performance data, including spectrum plots. SC

References

1. **Gary McClellan, Programma-II synthesised signal generator**, *Radio-Electronics* magazine, Aug & Sept 1981 (300kHz to 30MHz CW/AM signal generator, 10kHz tuning steps, 10-300mV output)
2. **G. Baars, PE1GIC, DDS RF Signal Generator**, *Elektor*, October 2003 (50Hz to 70MHz, CW/AM/FM, 1Hz to 1MHz tuning steps, 0 to -127dBm out)
3. **Ian Pogson, Solid state modulated RF test oscillator**, *Electronics Australia*, May 1979 (455kHz to 30MHz in four ranges, approximately 100mV output)
4. http://lea.hamradio.si/~s53mv/dds/theory.html
5. www.picmicrolab.com/ad9850-pic16f-interface-parallel-data-load/

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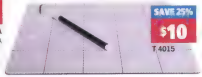

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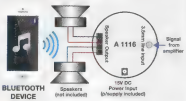

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Using e-Paper Displays

by Tim Blythman

Electronic paper or e-Paper displays (also known as E-Ink) are used in devices like e-Book readers and even to show product prices on the shelves in some shops. These displays are now becoming available as electronic modules, making them usable by hobbyists. In this article, we explain what they do, how to use them and where to get them.

E-Paper displays have very high contrast and good daylight readability with a wide viewing angle, and usually, require no power to maintain the display once set.

So they are well-suited to applications where display updates are infrequent.

While some e-Paper displays can show colours, most are black and white only, although this limitation also results in good contrast and keeps the control scheme simple.

We bought an e-Paper display, tested it out and wrote code to drive it from both an Arduino and Micromite.

Read on to see if an e-Paper display is something you would like to add to your next project!

How it works

While there are variations to the technology, many displays are based on electrostatically charged coloured particles.

Sometimes these are particles with one black side and one white side; in other cases, they are light particles suspended in a dark liquid.

An applied electric field rotates or moves the particles so that the apparent colour changes. Once the display has been updated, the displayed image will remain indefinitely (or at least until the display is powered up again and commanded to change) – see Fig.1.

The ability to hold the last state with no power consumption makes e-Paper displays ideal for e-Book readers or price displays. The high contrast ratio means that no backlighting is required, and practically zero power is consumed overall.

Thus e-Book readers can run for up to a month between charges, and shelf price displays can operate from a tiny button cell.

Limitations

Of course, if e-Paper displays had no downsides, we'd be seeing them everywhere. They cost more than monochrome LCD with a similar resolution and availability (at least to individuals) is still limited.

Also, as they are optimised for infrequent updates, they don't cope well with fast updates. The unit we tested took around 300ms for a so-called 'partial' refresh and over a second for a full refresh. So they're definitely not suitable for video playback.

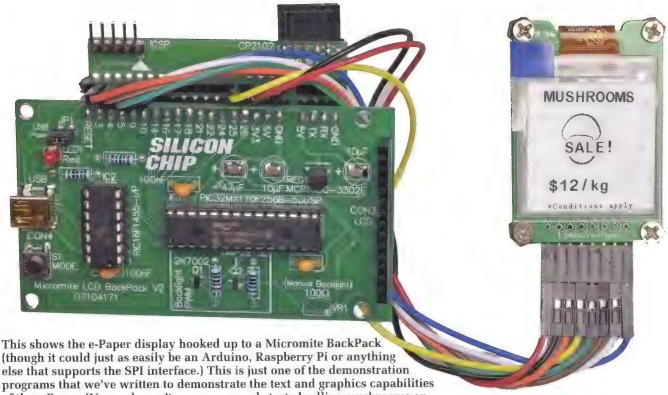
The difference between a partial and full refresh does not relate to whether some or all of the screen is refreshed, but rather how effectively the refresh occurs. A partial refresh is quicker, but may not entirely flip all of the pixels, resulting in 'ghosting' from the previous image.

A full refresh takes longer but is more thorough. If you have ever seen an e-Book reader updating and noticed that the display flashes from all black to all white before settling on a final image, that is a full refresh and it ensures that there are no remnants of the previous display left behind.

Colour e-Paper displays exist but are quite expensive. Interestingly, they use a subtractive colour system based on cyan, magenta and yellow (like printed books and magazines) rather than the additive system used by TVs and computer monitors, which mix red, green and blue light.

Many e-Paper controller ICs use high voltages to drive the display. Since electric field strength is proportional to voltage, it makes sense that a display driven with higher voltages will provide more effective updates.

We measured around 20V on our test



This shows the e-Paper display hooked up to a Micromite BackPack (though it could just as easily be an Arduino, Raspberry Pi or anything else that supports the SPI interface.) This is just one of the demonstration programs that we've written to demonstrate the text and graphics capabilities of the e-Paper. (No, we haven't gone crazy and started selling mushrooms on special at $12/kg – we're not sure how many we'd sell at that price anyway . . .)

module while the display was active. The data sheet includes a reference design which specifies a 25V-rated capacitor and an inductor-based boost circuit.

We found that the 3.3V rail on the Micromite sagged quite badly (down to 2.7V) while the display was updating, and the measured current draw was over 300mA.

Clearly, the low power requirement is subject to the proviso that there may be brief bursts of high current while the display is being updated.

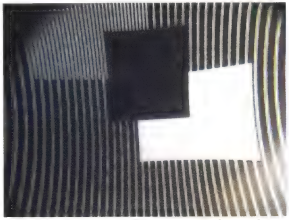
We think a charge-pump boost circuit may be better suited to this application, as the current needed to flip the pixels should be quite small.

Display use with no backlighting assumes that there is adequate ambient light for viewing the display.

For an e-Paper display to be useful in low light conditions, a separate source of illumination would be required, potentially negating the low power benefit (although it still may be more efficient than a backlit display, as less light would be required thanks to the high contrast).

Our e-Paper module

The module we tested is one of the smaller types available, with a 1.54in diagonal display having a square, 200x200 pixel active area. It has an 8-way header for control. The overall module measures 34x50mm and comes with a tapped spacer in each corner for mounting.



This close-up of the display shows that the pixels have quite blurry edges. There are also some small black dots visible on the white region. These are almost impossible to see at normal reading distances.

We sourced our unit from an online store at siliconchip.com.au/link/aapo, but several similar 200x200 pixel displays are available from other sources, and appear to use the same controller and command set.

The 8-way electrical header mentioned above consists of a set of pads spaced apart by 0.1in (2.54mm), to which we soldered a header socket, so we could use jumper wires for prototyping. But you could also plug it into a breadboard or into a socket on stripboard or an etched PCB.

The eight pins are for 3.3V power and ground, plus the SPI control bus (MOSI, SCK and CS) and a data/command (DC) control line, as well as a RESET input and BUSY pin. While most of these are found on other SPI-based display modules (eg, LCDs), the BUSY pin is not something we've seen before.

Fig.2 shows the reference schematic from the display data sheet (siliconchip.com.au/link/aapp). The controller IC is an IL3820, and we found its data sheet, too. See siliconchip.com.au/link/aapq.

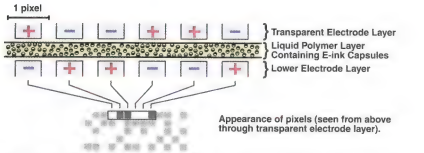


Fig.1: a typical e-Paper display consists of contrasting coloured capsules suspended between the electrodes. An applied electric field causes particles to move or rotate and the displayed colour to change.

This controller supports displays up to 320x240 pixels, as well as multiple serial and parallel data formats. Hence the I/O pins take on different roles depending on the data format.

On our module, the BS1 line of this IC is broken out to a small slide switch which can be used to toggle between 9-bit and 8-bit SPI mode. We have used 8-bit mode for our examples, which corresponds to the slide switch being set to the '0' position.

The display data sheet notes that the controller should not be interrupted while the display is being updated. Since this can take over a second, the BUSY pin provides a simple means to monitor when the controller is ready. The microcontroller can resume other tasks and check the BUSY pin to determine when the display controller is ready for another command.

Getting it going

We used an ESP8266-based, Arduino-compatible D1 Mini board for further testing. This is a WiFi-capable board which can be programmed using the Arduino IDE. We're using this because it has 3.3V I/O pins, which suits the I/O and power requirements of the e-Paper module.

It would be tricky to drive it using an Arduino with 5V I/Os like an Uno.

The supplier of the module provided a link to an open-source library for working with the displays. We have included this in our software download bundle. The library supports ESP8266 boards.

As is often the case, using the library was not straightforward. The library supports many different displays, but none of these were an exact match for the display we were using.

The library provides example code for around a dozen displays, including two with the same 200x200 pixel resolution as ours. Trying these, we were able to see some activity on the display, but it appeared to be a corrupted or distorted image.

Looking further into the library, we found that these two displays do not use the IL3820 controller IC. We found another example sketch that did use the IL3820, but it did was intended for a lower-resolution display than ours. It worked, but was not able to refresh the entire screen.

Given these two examples, we were confident we could write our own interface code from scratch and tried to do so. As well as using this library as a reference, we also had the aforementioned data sheet.

Display quirks

The 'quirks' we found are due to the nature of e-Paper displays. These are quite different from liquid crystal displays (LCDs). Like LCDs, the e-Paper displays need to be issued a series of commands at power-up before they are ready to show text or images.

Firstly, the display controller needs to be told how large the display is. While it may seem like a small detail, it's not something we've had to with other display controllers. As we mentioned, the IL3820 controller can work with displays up to 320x240 pixels, while our display is only 200x200 pixels.

We also found reference to a waveform lookup table (LUT) which needed to be loaded into the display. The library code examples actually had two LUT arrays, each 30 bytes long, labelled "full refresh" and "partial refresh".

The LUT waveform controls the display update sequence, so which array you use determines whether you get a full or partial display update.

There is a reference in the IL3820 datasheet as to what voltages these values correspond to, but the values from the library worked well enough that we did not try to change them.

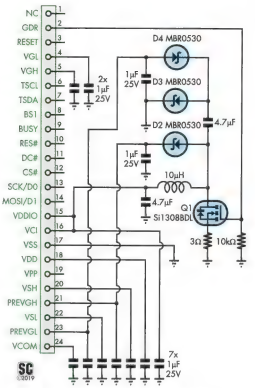


Fig.2: this reference schematic for the IL3820 e-Paper controller IC indicates that the controller doesn't need much external circuitry other than the boost circuit to generate a higher voltage for refreshing the display, and a handful of bypass capacitors.

The boost circuit shown in Fig.2 also needs to be activated by sending a command to the controller.

Given the high current consumption that we saw while the boost circuit was running, we tried turning this on immediately before sending the refresh command, and found that this worked well.

Our example code does this too.

Like many other displays, drawing is done by selecting an area of pixels within the display and then streaming bitmap data into that area.

As we've previously alluded, though, merely sending the new pixel data does not cause the display to update.

There is another short sequence of commands which updates the actual display based on the data which is in its memory buffer. It is this sequence which triggers the actual display refresh.

To shut down the boost circuit and save power, after the refresh sequence

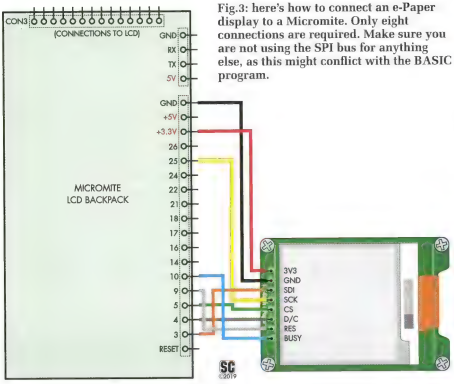


Fig.3: here's how to connect an e-Paper display to a Micromite. Only eight connections are required. Make sure you are not using the SPI bus for anything else, as this might conflict with the BASIC program.

is complete, we shut down the controller by pulling the reset pin low.

We found one more thing that was not obvious from reading the data sheet. There are two RAM buffers on the controller, and it alternates between them each time the display is refreshed.

Thus, it is quite easy to alternate between two images by doing nothing more than sending repeated refresh sequences.

Our code

We're providing two code examples, one for Arduino and one for Micromite. They both drive the display in the same manner.

When you run this code, the display first shows what appears to be various shades of grey, although the mid-shades are actually alternating patterns of light and dark pixels. The display has a nominal resolution of 184 DPI, which is around 7 pixels per millimetre, so dithering works quite well to produce intermediate tones. You have to be very close to the display to see the pixel patterns.

After a short pause, it shows the second display page, which is a comparison between two fonts and also shows the difference between white-on-black and black-on-white text.

We think that the black-on-white text is easier to read, perhaps because of its similarity to black ink printed on white paper which we are so familiar with.

The next page is full of text in a tiny font. Each character is around 1.5mm high, much smaller than the text you might find in a book or newspaper. The text is quite legible, although you may need to squint to read it.

The fourth page has larger text and is quite easy to read. You will have to look closely to see the individual pixels.

The next page is designed to look like what might be displayed on an electronic price ticket. There are different sizes of text and a bitmap image too. We used an online tool to convert images to C code for the Arduino example. It is at: www.digole.com/tools/PicturetoC_Hex_converter.php

For the Micromite example, we had to convert this data to a 32-bit format to simplify the code, which was an extra step, as well as converting it to a format suitable for MMBasic.

The final page display is similar in that it also shows an electronic price ticket, although this example uses the two RAM buffers to flash a banner across the image. As noted above, once the two RAM buffers have been filled, the refresh sequence is all that is needed to alternate between them.

Between each example page, the display is shut down (by pulling the reset pin low), then the code waits for a fixed period before repeating the initialisation code, to restart the display before the next update.

Connecting it up

To try out our example code, you will need a display and also a microcontroller module to connect it to.

We provided a link (above) to the online store where we bought ours. We have not tried any others, but if you find another 200x200 pixel e-Paper display which uses the IL3820 controller and has an eight-way connector, then there's a good chance that our code will work with it.

We have used the hardware SPI ports to drive the displays in both the Micromite and Arduino examples. These, and the other necessary connections, are noted near the top of the sample code. You can also refer to Figs.3 & 4 and the table of connections (Table 1) to wire up the display to your microcontroller.

The module will only work at 3.3V,

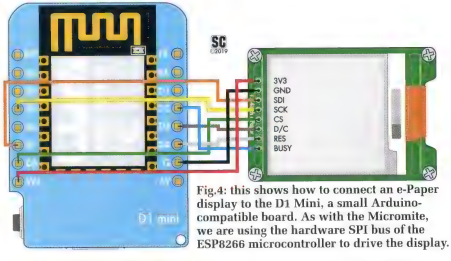


Fig.4: this shows how to connect an e-Paper display to the D1 Mini, a small Arduino-compatible board. As with the Micromite, we are using the hardware SPI bus of the ESP8266 microcontroller to drive the display.

so if using an Arduino board, make sure it's a type with 3.3V I/Os.

Loading the examples

Once you have made the necessary connections, you can try out our code.

Our example code does not need any external libraries to work (although the Arduino example has some included files in the sketch folder for fonts and images).

Open the code and upload it to your microcontroller board. You should see the display cycle through the different test screens described earlier.

Writing your own code

To write your own code, have a look at our examples and follow the sequence between two locations where the reset pin is pulled low.

Note that the module draws a reasonably high current while the boost circuit is running, which is switched on by the EPAPERINIT/epaperInit() function and then off when the reset pin is pulled low.

So we recommend that you run this complete sequence without interruption, minimising the time the boost circuit is active.

e-Paper display	Micromite BackPack V2	Arduino D1 Mini
3V3	3V3	3V3
GND	GND	G
SDI	3	D7
SCK	25	D5
CS	5	D8
D/C	4	D3
RES	9	D4
BUSY	10	D2

Table 1: e-Paper display connections required by example code

The display controller receives rows of eight pixels at a time, so there are only two orientations that can be used (normal and rotated 180°), although this should not cause any problems due to the square shape of the display – there is no 'landscape' or 'portrait' mode!

To see the effects of a full refresh versus a partial refresh, replace all of the

EPAPERSETFULLREFRESH/ epaperSetFullRefresh()

commands with

EPAPERSETPARTIALREFRESH/ epaperSetPartialRefresh()

commands.

What to do with an e-Paper display

We were impressed with how easy it was to get this display up and running, and we hope to find some good ideas as to how this type of display can be used in a practical project.

It is well-suited to the electronic Tide Chart we presented last July (siliconchip.com.au/Article/11142) as this only requires very infrequent display updates.

The e-Paper display would also be good for a weather display or even a web-connected public transport timetable, for similar reasons.

They would work well as programmable name badges, perhaps not even needing a power source while they are being worn.

We're dubious about using them in battery-powered applications as they seem to have very high peak current draw, despite being able to operate with practically zero power draw the rest of the module.

However, once the display is on the e-Paper it stays there until it is re-written, so you don't have to worry about continually supplying power to the module. SC

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Updating your car entertainment system? You will probably need this

Steering Wheel Audio Button to Infrared Adaptor

by John Clarke

If you upgrade the radio or 'infotainment' head unit in a car with push-button steering wheel controls, those controls may stop working. That's because many aftermarket head units do not support steering wheel controls, the implementation of which often varies between manufacturers and even between models. This adaptor lets you use most of those very handy controls with a wide range of aftermarket head units.

Once upon a time (would you believe way back in 1930?) car manufacturers started fitting car radios. Nothing fancy, mind you – just a basic AM receiver.

Over the years, buyers demanded more: push-button tuning, FM tuners, 8-track players, cassette players, CD/DVD players and so on. In more recent times, we've seen that expand to include auxiliary inputs, USB and SD-card readers, Bluetooth and even inbuilt navigation systems.

To control all this technology, "head units" were created – essentially a dedicated computer in its own right – with not just the source but such things as volume, radio station, track selection and more selected via push-buttons and, becoming more popular, an infrared remote control.

And then someone got the bright idea to incorporate those push-buttons into the steering wheel – and the Steering Wheel Controller (SWC) was born, offering remote control without taking your eyes off the road for very long (if at all).

Some head units incorporate a remote control input wire at the rear of the unit and are operated via a voltage or digital signal.

Fortunately, with our adaptor it doesn't matter which system the head unit supports (if any) – just so long as it also offers infrared remote control. Almost all modern head units do.

These handheld remotes are small and fiddly to use, and we don't recommend that they're used by the driver because they are too distracting. That's if the driver can find it in the first place: they have the annoying habit of falling down between the seats!

Our SWC Adaptor can operate the head unit using infrared control and it is, in turn, controlled by the steering wheel buttons. So you don't even need to open up your head unit to use it. You can feed the IR control signals in through the faceplate.

Note that some SWCs are digital; they may be connected via a Controller Area Network (CAN) bus or a proprietary system. These are not suitable for use with this adaptor. It works with controls where each switch connects a different resistance between a particular wire and chassis (0V) when pressed.

Before embarking on this project, it would be wise to check that your steering wheel controls are suitable for use with the SWC Adaptor. See the panel entitled "Are your steering wheel controls suitable?"

Features

- Compact unit, can be hidden away under or behind the dash or even inside the head unit
- Works with up to 10 resistance-based steering wheel buttons
- Controls head unit via infrared signals (requires remote control capability)
- Works with most head units (using NEC, Sony or RC5 infrared codes)
- Infrared receiver included for programming the function of each button
- Easy set-up by learning remote control codes for each steering wheel button
- Optional unmodulated infrared output for direct wire connection
- Two non-repeat buttons for special functions (see text)

We housed the adaptor in one of Jaycar's flanged UB5 Jiffy boxes (Cat HB6016) because it makes mounting that much easier.

The only other requirement is that head unit uses one of these three infrared remote control protocols: NEC, Sony or Philips RC5. Virtually all head units with remote control use one of those three.

By far the most common is the NEC format. This is used by most head units manufactured in Asia including Pioneer, Akai, Hitachi, Kenwood, Teac, and Yamaha plus Germany-based Blaupunkt.

The Sony protocol is the next most common. The RC5 format is used by Philips and some other European brands, although we have seen some Philips products which use the Sony format

Presentation

The SWC Adaptor comprises a small PCB which can fit into a small Jiffy box. It's connected to an ignition-switched 12V supply and the steering wheel control wire. It provides two outputs: one to drive an infrared LED to operate the head unit, and a second for an optional direct wire connection which can control the head unit directly, without the need for an infrared transmitter. More on that later.

In use, the SWC Adaptor can be programmed to map up to ten steering wheel buttons to separate infrared codes to send to the head unit. Once programmed, it can be hidden away (eg, under or behind the dash) and the steering wheel buttons can be used to control the head unit while the vehicle ignition is on.

Circuit description

Fig.1 shows the circuit of the SWC Adaptor. It is based around microcontroller IC1, a PIC12F617-I/P. This

Are your steering wheel controls suitable?

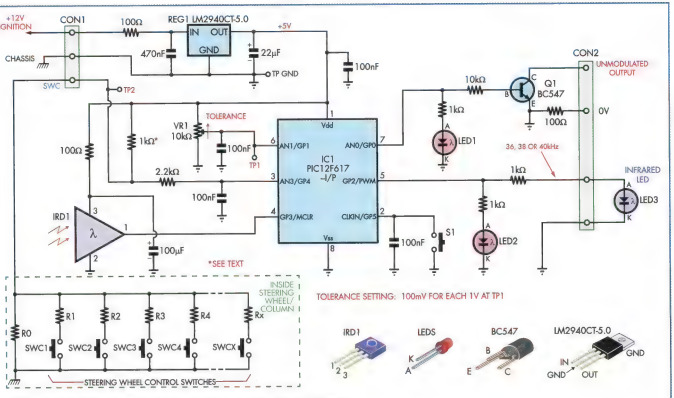
Before deciding to build the SWC Adaptor, you will need to check that the steering wheel control switches are the type that switch in a resistance rather than digital types that produce a series of digital (on and off) signals when the switch is pressed. We also assume that the head unit you intend to use has infrared remote control and uses one of the standard protocols as mentioned in the article.

To check the SWC switches, your original equipment head unit will offer clues as to which wire this is. There should be a connection diagram on the head unit. Or you can find the wire using a vehicle wiring diagram.

With the ignition off and the SWC wire not connected to the head unit, connect your multimeter leads between that wire and vehicle chassis. Set the multimeter to read resistance. The resistance may read very high ohms when the SWC switches are all open or it may be a few thousand ohms. Pressing each SWC switch in turn should show a different resistance reading.

For example, our test vehicle showed a resistance of 3.5kΩ with all switches open. Then the switch readings were 160Ω, 79Ω, 280Ω, 450Ω, 778Ω and 1.46kΩ for each of the six switches. So these readings prove that the steering wheel controls are the analog type that switch in resistance and so is suitable for use with the SWC Adaptor.

If you do not get resistance changes, check that you are monitoring the correct wire and that the chassis connection is good. If the switches still do not show resistance, they might be producing a digital signal when the vehicle ignition is on. The steering wheel controls on your vehicle are therefore not suitable for use with the SWC Adaptor.



STEERING WHEEL CONTROL ADAPTOR

Fig.1: IC1 monitors the steering wheel controls via analog input AN3, while also sensing tolerance adjustment trimpot (VR1) at analog input AN1. The state of switch S1 is monitored at digital input GP5 and the signal from infrared receiver IRD1is monitored at digital input GP3. To control the vehicle head unit, IC1 produces remote control code pulses at its pin 5 PWM output. These codes are transmitted in 36-40kHz bursts, to drive infrared LED3. An identical, non-modulated signal is also sent to the GP0 digital output (pin 7). This has the advantage that you can wire it in place of the infrared receiver, for a direct wired connection to the head unit.

monitors the steering wheel controls via analog input AN3, while also sensing tolerance adjustment trimpot (VR1) at analog input AN1, the state of switch S1 at digital input GP5 and the signal from infrared receiver IRD1 at digital input GP3.

To control the vehicle head unit, IC1 produces remote control code pulses at its pin 5 PWM output. These codes are transmitted in 36-40kHz bursts, to drive infrared LED3. An identical, non-modulated signal is also sent to the GP0 digital output (pin 7). This has the advantage that you can wire it in place of the infrared receiver, for a direct wired connection to the head unit.

The exact modulation frequency depends on the infrared protocol that the unit is set up for. It is 36kHz for the Philips RC5 protocol, 38kHz for the NEC protocol and 40kHz for the Sony protocol.

In more detail, the SWC input at CON1 has a 1kΩ pull-up resistor to the 5V supply. This forms a voltage divider across the 5V supply, in combination with the steering wheel switch resistances, giving a different voltage at analog input AN3 (pin 3) of IC1 for each switch that is pressed.

This voltage is applied to the AN3 input via a low pass filter comprising a 2.2kΩ resistor and 100nF capacitor. IC1 converts the 0-5V voltage to a digital value between 0 and 255.

So for example, a 2.5V signal would be converted to a value of 127 or 128, around half of the maximum value of 255.

As for the AN1 input, the 0-5V from trimpot VR1's wiper is converted to a digital value. The 0-5V range of VR1 is mapped in software to a 0-500mV range of tolerance.

So If VR1 is set midway at 2.5V, the tolerance setting is 250mV (1/10th of the wiper voltage, measured at TP1). So the SWC input voltage can differ from its stored value by up to ±250mV and still be recognised as that particular switch.

Tolerance is essential since the SWC voltage may vary with temperature due to resistance variation in the switch resistor, and switch contact resistance can also cause voltage variation.

Having detected a valid SWC button press, IC1 activates its pin 5 and 7 outputs to produce the appropriate remote control code to send to the vehicle head unit.

The modulated output at pin 5 has a 50% duty cycle. It can drive an infrared LED via a 1kΩ resistor and CON2. LED2 is also driven by the PWM output during transmissions, as a visible indication.

The unmodulated output from pin 7 drives the base of NPN transistor Q1 via a 10kΩ resistor and also LED1, via a 1kΩ resistor. The collector of Q1 is open so that it can connect directly to the IR receiver in the head unit. The emitter is isolated from ground via a 100Ω resistor to reduce current flow due to the possibly differing ground potentials in this unit and the head unit.

Fig.2 shows the output signals at pins 5 (yellow) and the collector of Q1 (cyan), demonstrating the 36-40kHz modulation applied to pin 5 but not Q1's collector. In this case, the NEC protocol is being used so the modula-

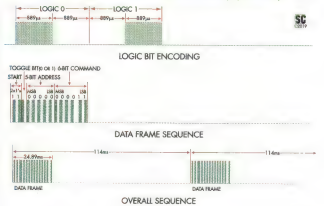
Infrared Coding

Most infrared controllers switch their LED on and off at a modulation frequency of 36-40kHz in bursts (pulses), with the length of and space between each (pauses) indicating which button was pressed. The series of bursts and pauses is in a specific format (or protocol) and there are several commonly used. This includes the Manchester-encoded RC5 protocol originated by Philips.

There is also the Pulse Width Protocol used by Sony and Pulse Distance Protocol, originating from NEC.

For more details, see application note AN3053 by Freescale Semiconductors (formerly Motorola): siliconchip.com.au/link/aapv

Philips RC5 (Manchester-encoded) (36kHz)



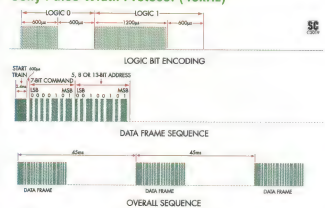
For this protocol, the 0s and 1s are transmitted using 889µs bursts and pauses at 36kHz. A '1' is an 889µs pause then an 889µs burst, while a '0' is an 889µs burst followed by an 889µs pause. The entire data frame has start bits comprising two 1s followed by a toggle bit that could be a 1 or 0. More about the toggle bit later.

The data comprises a 5-bit address followed by a 6-bit command. The most significant command bits come first.

When a button is held down, the entire sequence is repeated at 114ms intervals. Each repeat frame is identical to the first. However, if transmission stops, then the same button is pressed again, the toggle bit changes. This informs the receiver as to how long the button has been held down.

That's so it can, for example, know when to increase volume at a faster rate after the button has been held down for some time.

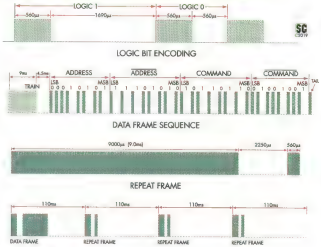
Sony Pulse Width Protocol (40kHz)



This is also known also as SIRC, which is presumably an acronym for Sony Infra Red Code. For this protocol, the 0s and 1s are transmitted with a differing overall length. The pause period is the same at 600µs, but a '1' is sent as a 1200µs burst at 40kHz, followed by a 600µs pause, while a '0' is sent as a 600µs burst at 40kHz followed by a 600µs pause.

The entire data frame starts with a 2.4ms burst followed by a 600µs pause. The 7-bit command is then sent with the least significant bits first. The address bits follow, again with least significant bits first. The address can be 5-bits, 8-bits or 13-bits long to make up a total of 12, 15 or 20 bits of data. Repeat frames are the entire above sequence sent at 45ms intervals.

NEC Pulse Distance Protocol (PDP) (38kHz)



For the NEC infrared remote control protocol, binary bits zero and one both start with a 560µs burst modulated at 38kHz. A logic 1 is followed by a 1690µs pause while a logic 0 has a shorter 560µs pause. The entire signal starts with a 9ms burst and a 4.5ms pause.

The data comprises the address bits and command bits. The address identifies the equipment type that the code works with, while the command identifies the button on the remote control which was pressed.

The second panel shows the structure of a single transmission. It starts with a 9ms burst and a 4.5ms pause. This is then followed by eight address bits and another eight bits which are the "one's complement" of those same eight address bits (ie the 0s become 1s and the 1s become 0s). An alternative version of this protocol uses the second series of eight bits for extra address bits.

The address signal is followed by eight command bits, plus their 1's complement, indicating which function (eg volume, source etc) should be activated. Then finally comes a 560µs "tail" burst to end the transmission. Note that the address and command data is sent with the least significant bit first.

The complementary command bytes are for detecting errors. If the complement data value received is not the complement of the data received then one or the other has been incorrectly detected or decoded. A lack of complementary data could also suggest that the transmitter is not using the PDP protocol.

After a button is pressed, if it continues to be held down, it will produce repeat frames. These consist of a 9ms burst, a 2.25ms pause and a 560µs burst. These are repeated at 110ms intervals.

The repeat frame informs the receiver that it may repeat that particular function, depending on what it is. For example, volume up and volume down actions are repeated while the repeat frame signal is received but power off or mute would be processed once and not repeated with the repeat frame.

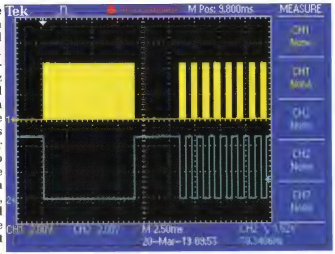


Fig.2 shows the output signals at pin 5 of IC1 (yellow) and the collector of Q1 (cyan), demonstrating the 36-40kHz modulation applied to pin 5 but not on Q1's collector. Note that the collector has a 10kΩ pullup resistor to 5V in order to be able to show the voltage swing from Q1. In this case, the NEC protocol is being used so the modulation is at 38kHz.

tion is at 38kHz.

The unit is set up using infrared receiver IRD1. This three-pin device incorporates an infrared photodiode, amplifier and automatic gain control plus a 38kHz bandpass filter to accept only remote control signals, within a few kHz of the carrier frequency.

The filter is not narrow enough to reject the 36-40kHz frequencies that could be produced by various different remote control units.

IRD1 removes the carrier, and the resulting digital signal is fed to the GP3 digital input of IC1 (pin 4), ready for code detection.

IRD1 runs from a 5V supply filtered by a 100Ω resistor and 100µF capacitor, to prevent supply noise causing false IR code detection.

Pushbutton switch S1 is bypassed with a 100nF capacitor to filter transients and for switch debouncing. The voltage at digital input GP5 is held at 5V via a weak pull-up current, internal to IC1.

When S1 is pressed, GP5 is pulled low to 0V and IC1 detects this. S1 is used during programming and to set a new tolerance adjustment.

The circuit is powered from the vehicle's 12V ignition-switched supply, fed in via CON1. This supply goes through an RC low-pass filter (100Ω/470nF) and then to automotive 5V linear regulator REG1, to power IC1 and the rest of the circuitry.

The LM2940CT-5.0 regulator will not be damaged with a reverse supply connection or transient input voltage up to 55V, for less than 1ms.

These situations can occur with some regularity in vehicle supplies, eg, with an accidentally reversed battery or when windscreen wiper motors switch off etc.

Construction

The SWC Adaptor is built on a PCB coded 05105191, measuring 77 x 47mm. It fits into a UB5 Jiffy box. The overlay diagram, Fig.3, shows how the components are fitted.

Start with the resistors. These are colour coded as shown in the parts list. It's a good idea to use a multimeter to check the value of each set of resistors before fitting them, as the colour codes can be confused.

We recommend using a socket for IC1. Take care with the orientation when installing the socket and IC1.

The capacitors can be fitted next. The electrolytic types must be installed with the polarity shown, with the longer positive lead towards the top of the PCB. The polyester capacitors (MKT) can be mounted with either orientation on the PCB.

REG1 can be then installed. It's mounted horizontally on the PCB. Bend the leads so they fit the PCB holes with the tab mounting holes lining up. Secure the regulator to the PCB with the screw and nut before soldering the leads.

The infrared receiver (IRD1) also mounts horizontally, with the lens facing up and with the leads bent through 90° to fit into the holes.

Trimpot VR1 is next. It has a value of 10kΩ and may be marked as either 10k or 103. Follow that with the LEDs (LED1 and LED2). The anode (longer lead) goes into the hole marked "A" on the PCB. The LEDs should be installed with the base of their lenses about 5mm above the PCB. Switch S1 can also be fitted now.

Next, solder transistor Q1 to the PCB, with its flat side facing as shown. You may need to bend its leads out (eg, using small pliers) to fit the pad pattern on the board.

Now install the two screw terminal blocks. CON1 is mounted with the wire entry holes towards the left-hand edge of the PCB while CON2 should be fitted with the wire entries toward the right-hand edge. You can make up a 4-way terminal by dovetailing two 2-way terminals.

If you are using a socket for IC1 as suggested, plug in the chip now, ensuring that its pin 1 dot is oriented as shown in Fig.3.

Housing it

The SWC Adaptor may fit inside the head unit if there is room, or you can mount it outside the head unit in a UB5 box. We used a flanged box that has an extended length lid with extra mounting holes. This makes it easier to

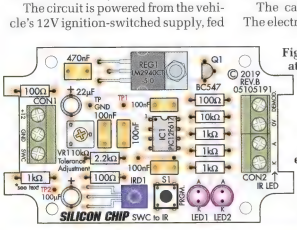
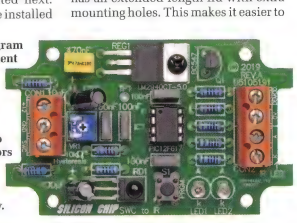


Fig.3: the overlay diagram at left shows component placement while the matching fully component installed PCB is shown at right. Make sure the two electrolytic capacitors and IC1 are correctly oriented with the shown polarity.



mount in the car, under the dashboard is the logical location.

Alternatively, a standard UB5 box can be used instead, or the unit can be wrapped in insulation and cable tied in position.

If fitting it into a box, drill holes at either end to fit the cable glands which allow the power supply and infrared LED wiring to pass through.

There are cut-outs in the PCB to accommodate the gland nuts which go inside the box. But note that these nuts must be oriented correctly, with two of the sides vertical, so they will fit into the recesses in the board.

The PCB is mounted in the box on four 12mm-long M3 tapped spacers, using eight machine screws. Mark out and drill the 3mm holes for PCB mounting while you are making the holes for the cable glands.

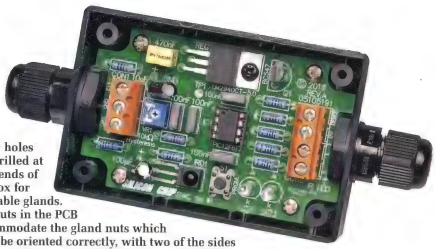


Fig.4: holes are drilled at both ends of the box for the cable glands. Cut-outs in the PCB accommodate the gland nuts which must be oriented correctly, with two of the sides vertical, so they will fit into the recesses in the board. The PCB is mounted in the box on four 12mm-long M3 tapped spacers and attached using M3 screws

Installation

The SWC Adaptor is wired into the vehicle so that it gets +12V power when the ignition is switched on. Virtually all head units have connecting wires carrying 0V (GND) and ignition-switched +12V, so you can tap into the supply there.

Just make sure the +12V wire has power with the ignition on and not with the ignition off.

The SWC input on the SWC Adaptor connects to the steering wheel control wire. You should already know where to tap into it from the previous test where you determined that your steering wheel controls are suitable for use with this unit.

The SWC Adaptor has two pairs of output wires: one pair to drive an external infrared LED (LED3) and another connecting to the collector and emitter of the transistor which provides the unmodulated output. You can use either to control the head unit. Each option has advantages and disadvantages.

The infrared LED approach has the advantage that the head unit does not need to be opened up; the infrared LED is simply placed over the infrared receiver on the head unit. The disadvantage is that the wiring to this LED, and the LED itself, will be visible.

The easiest way to do this is to use a premade IR Remote Control Extension Cable. These are available from Jaycar (see parts list). This has an infrared LED already mounted in a small neat housing, with a long lead.

You will need to figure out how to route that cable from the SWC Adaptor mounting location to the IR receiver on the head unit.

Adhesive wire saddles are useful for keeping this wiring neat.

The Jaycar IR extender has a 3.5mm jack plug which you can cut off, as it isn't needed. The LED anode wire is the one which was connected to the jack plug tip. You can also get similar extenders from eBay, AliExpress, Kogan etc, most of which have bare wire ends. Whichever one you use, wire it to the A and K terminals of CON2.

It's then just a matter of sticking the LED emitter package to the front of your head unit, directly in front of the infrared receiver, using its own self-adhesive pad.

If you do not know where the infrared receiver is, it will be in an area free from switches and knobs.

The front panel may have a purple-looking area over the infrared receiver, different in appearance from the rest of the panel.

If you still can't figure it out, you will need to test the unit while moving the transmitter around the panel until you find a location where it works reliably. You can then stick it in place.

Tweaking the button sensing

Once you have the unit wired up to power and the steering wheel controls, it is a good idea to perform some checks to make sure it is sensing the steering wheel buttons accurately.

The Adaptor button sensing input includes a 1kΩ pull-up resistor to 5V. This is shown with an asterisk both on the circuit and PCB. This resistor may need to be changed in some vehicles to give reliable button detection and discrimination.

To check it, monitor the voltage between TP GND and TP2 when the unit is powered up, pressing each steering wheel button in turn.

On our test vehicle, we measured 3.93V with switches open, then 0.383V, 0.708V, 1.11V, 1.59V, 2.2V and 2.98V when each of six switches was pressed individually. So we had reasonable steps of more than 300mV between each voltage. The unit's tolerance should then be set to half that value; in this case, 150mV or less. So we adjusted VR1 for 1.5V at TP1.

But we could have improved the voltage range if the 1kΩ resistor was changed to 510Ω. That would give 4.37V with switches open and 0.67V, 1.19V, 1.77V, 2.34V, 3.02V and 3.7V with each pressed individually. That would give us a minimum step of at least 500mV and so the tolerance value could be set to 250mV (2.5V at TP1).

But as long as the tolerance can be set to at least 100mV (ie, at least 200mV between the two closest voltage readings), we would consider that acceptable.

If your steering wheel control switches provide a voltage range that differs significantly from ours, you may benefit from adjusting the 1kΩ resistor value. If your voltage readings are mostly low, try using a lower value, while if your readings are all on the high side, try using a higher value. But don't go below 200Ω as you then risk damaging the resistors in your steering wheel.

Using the unmodulated output

The advantage of using the unmodulated output from the SWC Adaptor is that it can be wired internally to the head unit, so the wiring may be able to

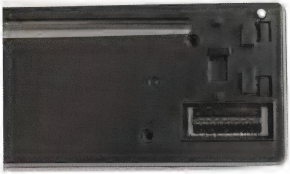


Fig.5 (above) shows the multi-way connector which is used to connect the front panel to the head unit.

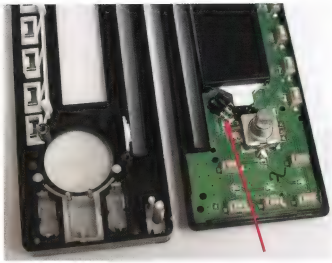


Fig.6 (at right) shows the opened up the front panel of the head unit and the location of the infrared receiver (arrowed). But this is not the best location to connect the wire.

be hidden. Usually, only a single wire needs to be connected to the infrared receiver on the head unit. This wire can pass out the back of the head unit and routed to the SWC Adaptor.

The disadvantage of this approach is that you need to open up the head unit, find the infrared sensor output and solder the wire to it. How this is done is best shown in the accompanying photos.

In Fig.6, we've opened up the front panel of the head unit and located the infrared transmitted (arrowed). But this is not the best location to connect the wire.

Fig.5 shows the multi-way connector which is used to connect the front panel to the head unit.

To figure out which pin carried the infrared receiver signal, we plugged the front panel back into the head unit and opened its case, then located where the front panel connector is terminated (see Fig.7). We then powered it up using a 12V DC source and connected a DMM set to measure volts between 0V and each pin at the rear of the front panel in turn.

Look for a pin which measures around 5V, then measure its voltage while an infrared transmitter is placed in front of the unit and a button held down, so it is transmitting. If you have the correct pin, that voltage reading should drop slightly while the infrared remote control transmitter is active. In our case, we found that it dropped from 5V to 4.75V during infrared reception.

The arrowed pin in Fig.7 is the one that we determined carries the infrared signal, and this is where we soldered the wire.

You could use an oscilloscope to look for the pulses from the infrared receiver; however, the multimeter method is easier and generally works well.

The SWC Adaptor output includes a 0V connection for the unmodulated output. This can be wired to a ground connection on the same multi-pin connector. However, this should not be necessary as the infrared receiver on the head unit should have its ground pin connected to the head unit chassis and would be at the same potential as the 0V connection on CON1.

If you have problems with the unmodulated connection working, try connecting a wire between these two points to see if that solves it.

Setting up the unit

Now you need to decide what functions you want from each switch on the steering wheel. Typically, this would include volume up and down, source selection, next and previous file/track/frequency/station and power on/off.

You are not restricted to the original purposes of each switch, although it would be less confusing to do so. You can use each switch to perform any of the functions available on the handheld remote control supplied with your head unit.

For some buttons, you may want the function to repeat if held down (eg, volume up/down) but with others, you may not (eg, source selection or on/off).

We found that with some head units, holding down the source selection button would result in nothing happening. You would have to press the button only for a short period to switch to the next source. That's not ideal when using steering wheel buttons. So we have included a feature in the SWC Adaptor where two out of the 10 possible buttons will not generate repeat codes even if held down.

So it's just a matter of assigning functions which may have this shortcoming on your head unit to those two button positions.

This would generally include source selection, power on/off, radio band change or mute. None of these need the repeat function.

You can test whether this is necessary by holding those buttons down on your infrared remote control and seeing whether the unit behaves as desired, or not.

Fig.7: the arrowed pin in is the one that we determined carries the infrared signal, and this is where we soldered the wire.

Programming the button functions

You can now match up the voltages produced by each steering wheel button to the desired infrared function. You can program up to 10 switches. It does not matter what order you program each switch, and you don't have to use all 10. The non-repeat feature mentioned above applies to switches nine and 10, so you can skip some positions if you don't have 10 buttons but need this feature.

All of the programmed infrared codes must use the same infrared protocol (NEC, Sony and RC5 are supported – see overleaf).

That should not be a problem given that your head unit remote control will be using one protocol for all of its buttons – and most likely, one of those supported by this unit.

To enter the programming mode, hold down S1 while switching on the vehicle ignition. Entering programming mode clears any previous programming.

So you must program the functions of all switches each time this mode is invoked. Upon the release of S1, LED1 will flash once, indicating that the SWC Adaptor is ready to programming the first switch function.

Point the handheld remote toward the infrared receiver on the SWC Adaptor and press the required function button. LED2 should light up. If it does not, it is possible that your handheld remote does not use one of the three supported protocols. LED2 will light up continuously for codes received in the NEC protocol. It will flash off once and then on for the Sony protocol and flashes off twice for RC5.

Now press and hold the steering wheel switch that you want to assign to that function, then press S1 on the SWC Adaptor. The input voltage for that switch and the infrared code will then be stored in permanent flash memory for that switch position. LED1 will then flash twice, to indicate that the Adaptor is ready to accept the infrared code for the second switch function.

Continue programming each switch for the function required. Each time you press S1, LED2 will flash a certain number of times, indicating the next switch number that is ready to be programmed. You can press S1 again to skip a position that you don't want to assign (eg, if you have less than ten steering wheel buttons). Once the tenth position is programmed, the SWC Adaptor will stop and not respond.

Switch off power and when you then switch it back on again, without pressing S1 on the unit, the SWC Adaptor will begin normal operation, reproducing the stored infrared code each time one of the selected steering wheel buttons is pressed.

This also applies if you don't program all ten positions; merely switch off the ignition when you have finished programming all the functions that are required.

To use the special non-repeat feature at positions nine and ten, you can skip over the earlier positions using extra presses of S1 to reach them if you are not programming all 10 functions. SC

Parts List – Steering Wheel Control Adaptor

1 PCB coded 05105191, measuring 77 x 47mm
1 UB5 Jiffy box (optionally with flange)
1 3-way PCB mount screw terminal with 5.08mm spacing (CON1)
2 2-way PCB mount screw terminals with 5.08mm spacing (CON2)
1 DIL-8 IC socket
1 momentary SPST pushbutton switch [Altronics S1120, Jaycar SP-0600] (S1)
9 M3 x 6mm pan head machine screws
1 M3 hex nut
4 M3 tapped x 12mm spacers
2 IP65 cable glands for 3-6.5mm wire

Semiconductors
1 PIC12F617-I/P microcontrollerprogrammed with 1510519A (IC1)
1 LM2940CT-5.0 5V atomotiveregulator (REG1)
1 Infrared receiver [Jaycar ZD1952 or ZD1953, Altronics Z1611A] (IRD1)
1 BC547 NPN transistor (Q1)
2 3mm high brightness red LEDs (LED1,LED2)
1 Infrared Remote Control Receiver Adaptor Extender Extension Cable [Jaycar AR1811 or similar] with adhesive backing for direct mount over IR sensor (LED3)

Capacitors
1 100µF 16V PC electrolytic
1 22µF 16V PC electrolytic
1 470nF 63V MKT polyester *(code 473, 0.47 or 470n)*
4 100nF 63V MKT polyester *(code 103, 0.1 or 100n)*

Resistors (0.25W, 1%)
1 10kΩ *(code: brown black orange brown or brown black black red brown)*
1 2.2kΩ *(code: red red red brown or red red black brown brown)*
4 1kΩ *(code: brown black red brown or brown black black brown brown)*
3 100Ω *(code: brown black brown brown or brown black black black brown)*
1 10kΩ miniature horizontal mount trim pot (VR1) *(may have code 103)*

Miscellaneous
Automotive wire, solder, connectors, self tapping screws etc.

Fig.8: the front panel for the SWC Adaptor can be downloaded as a .pdf from our website and printed onto paper, transparent film or adhesive-backed vinyl. See www.siliconchip.com.au/Help/FrontPanels for details.

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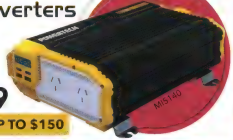

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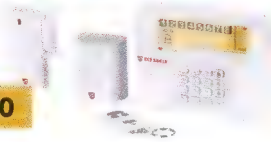

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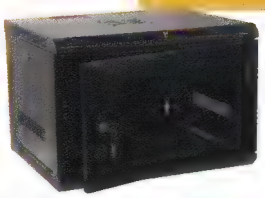

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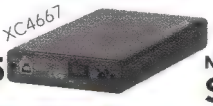

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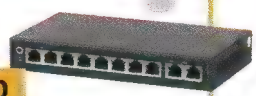
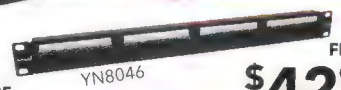


10-Port gigabit PoE network switch
8 × PoE-enabled and 2 × standard gigabit ports. Deliver up to 120W of power. Ultra-fast data transfer. Automatic PoE detection. YN8049 **WAS $229**



24-Port rack mount patch panels
Cat 5E Panels YN8046 **WAS $49.95**
NOW $42.95 SAVE $7
Cat 6 Panel YN8048 **WAS $69.95**
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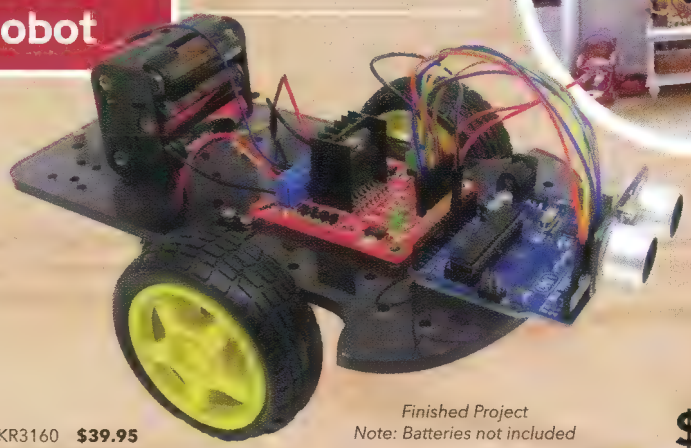
PROJECT:
DIY wall dodging robot

This little robot is fitted with an ultrasonic sensor which it uses to help navigate its surroundings. When it detects an object in front, it backs up, turns a little and then continues on its way.

SEE STEP-BY-STEP INSTRUCTIONS AT:
www.jaycar.com.au/diy-dodging-robot



Finished Project
Note: Batteries not included

WHAT YOU NEED:

2WD motor chassis robotics kit	KR3160	**$39.95**
Duinotech UNO r3 Development Board	XC4410	**$29.95**
Stepper Motor Controller Module	XC4492	**$14.95**
Dual Ultrasonic Sensor Module	XC4442	**$7.95**
150mm Plug to Socket Jumper Leads - 40 pieces	WC6028	**$5.95**
6x AA Battery Holder	PH9206	**$2.35**

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KJ9340

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Maker Kit 17-piece KJ9310 **WAS $119 NOW $99 SAVE $20**
Ultimate Kit 32-piece KJ9300 **WAS $149 NOW $119 SAVE $30**

NOW **$39.95**
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Short circuits 1 book and project kit
A great way to teach kids electronics - no soldering required! Kit includes baseboard, springs and components to make 20+ projects. KJ8502 **WAS $44.95**

NOW **$34.95**
SAVE $15

4WD Motor chassis robotics kit for Arduino® or pcDuino®
Includes motors, wheels, tyres and two pre-drilled mounting plates. Motor voltage: 5-10VDC. KR3162
WAS $49.95

NOW JUST **$39.95**
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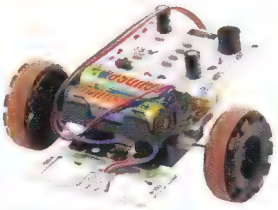
Hydraulic robot arm kit
No motors, no batteries required. 12 easy to build models. Lift up to 50g. Ages 8+.
KJ8997 **WAS $59.95**
ALSO AVAILABLE:
Motorised Robot Arm Kit KJ8995
WAS $139 NOW $119 SAVE $20

NOW **$37.95**
SAVE $7



PC programmable line tracer kit
An educational introduction to the world of robotics and programming. Use either programming or line tracing mode. Requires some tools and batteries. Ages 12+. KJ8906 **WAS $44.95**

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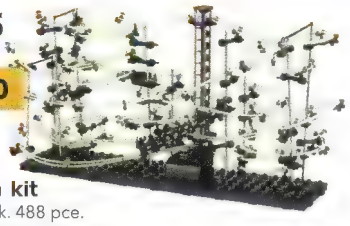
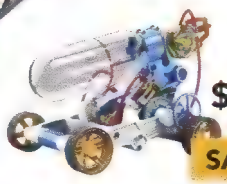
SAVE $10



Space rail construction kit
Glows in the dark. 488 pce. Multi-fit baseboard. C batteries required. KJ9001 **WAS $49.95**



NOW **$29.95**
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Air powered car kit
Operates entirely using air. Travels up to 80m on one single tank. Ages 10+.
KJ8967 **WAS $49.95**

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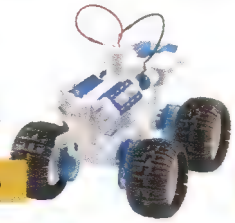

Salt water fuel cell engine car kit
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KJ8960 **WAS $24.95**

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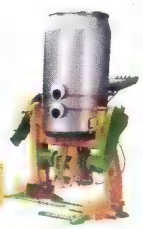

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Helps dissipate extraneous heat. Self adhesive pads for peel and stick use. Pack of 2. HH8584 **WAS $7.95**

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Basic Black XC9002 **Clear Acrylic** XC9004
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Quickbrake brake light warning kit

It detects when your foot quickly lifts off the accelerator pedal and activates your brake lights before your foot has even touched the brake pedal. Suitable for 12V vehicle systems. Short form kit includes PCB and components only.
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See website for details.

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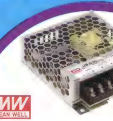

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TERMS AND CONDITIONS: FREWARDS / NERD PERKS CARD HOLDERS FREE GIFT. % SAVING DEALS. DOUBLE POINTS & MEMBERS OFFERS Jaycar Rewards / Nerd Perks membership at time of purchase. Refer to website for Rewards/ Nerd Perks Card T&Cs. Page 4: Nerd Perks Project Kit: DIY Wall Dodging Robot for $69.95 when purchased as a bundle (1 x KR3160, 1 x XC4410, 1 x XC4492, 1 x XC4442, 1 x WC6028, 1 x PHP206). Page 5: Raspberry Pi Bundle includes 1 x XC9001 + 1 x XC9022 + 1 x BM7160 + 1 x MP3536 & 1 x XC4989 for only $159. Page 6: Nerd Perks members 20% OFF Meanwell Enclosed Power supplies applies to LRS, RS & RD models. Nerd Perks members 25% OFF Sensor & Linker Modules apply to Jaycar 103D - product category excluding XC4442 and XC9022. Page 7: 50% OFF Conical tips (TS1442 or TS1441) & replacement sponge (TS1445). 20% OFF Filament applies to all 1.75mm PLA filament.

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Arrival dates of new products in this flyer were confirmed at the time of print but delays sometimes occur. Please ring your local store to check stock details. Occasionally there are discontinued items advertised on a special / lower price in this promotional flyer that has limited to nil stock in certain stores, including Jaycar Authorised Stockist. These stores may not have stock of these items and can not order or transfer stock. Savings off Original RRP. Prices and special offers are valid from catalogue sale 24.5.19 - 23.6.19.

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Upper Caboolture, Qld 4510
Tel: (07) 5330 3095
Web: www.picokit.com.au

Mouser QPF4528 FEM for IoT

Mouser Electronics, Inc is now stocking the QPF4528 front end module (FEM) from Qorvo. Designed for Internet of Things (IoT) systems based on Wi-Fi 6, the 5GHz FEM offers a compact form factor and integrated matching to minimize layout area in applications such as wireless routers, set top boxes, and access points.

It integrates a 5GHz power amplifier, regulator, SPDT switch, low noise amplifier with bypass mode, RF coupler and voltage power detector into a single device. It boosts linear power transmission without increasing power dissipation, enabling higher-performance Wi-Fi 6 (802.11ax) enterprise access points in smaller form factor designs.

The QPF4528 FEM allows up to 8×8 multiple-input multiple-output (MU-MIMO) in both conventional and Power over Ethernet (PoE) systems, offering enhanced capacity and efficiency and improved speed.

Contact:
Mouser Electronics
Unit 701-3,7F LU Plaza, 2 Wing Yip St
Kwun Tong, Kowloon Hong Kong
Tel: +852 3756-4700
Web: au.mouser.com

Microchip's new dsPICs mean larger, more robust applications

Microchip's new **dsPIC33CH512-MP508** dual-core DSC enables support for applications with larger program memory requirements.

This family expands the recently introduced dsPIC33CH with Flash memory growing from 128kB to 512kB and triples the program RAM from 24kB to 72kB. This enables support for larger applications with multiple software stacks or larger program memory, such as automotive and wireless charging applications. More memory is needed to accommodate AUTOSAR software, MCAL drivers and CAN-FD peripherals in automotive applications.

The **dsPIC33CK64MP105** single-core DSC extends the recently introduced dsPIC33CK family with a cost-optimized version for smaller memory and footprint applications, offering up to 64kB Flash memory and 28- to 48-pin packages. Package sizes are available as small as 4mm x 4mm. This compact device offers the ideal combination of features for automotive sensors, motor control, high-density DC-DC applications or stand-alone Qi transmitters.

All devices in the dsPIC33C family include a fully featured set of functional safety hardware to ease ASIL-B and ASIL-C certifications in safety-critical applications.

Functional safety features include multiple redundant clock sources, Fail Safe Clock Monitor (FSCM), IO ports read-back, Flash Error Correction Code (ECC), RAM Built-In Self-Test (BIST), write protection, analog peripheral redundancies and more. A robust set of CAN-FD peripherals, along with support for 150°C operation, make these devices ideally suited for use in extreme operating conditions such as under-the-hood automotive applications.

Contact:
Microchip Technology Inc
Unit 32, 41 Rawson St Epping NSW 2121
Tel: (02) 9868 6733
Website: www.microchip.com

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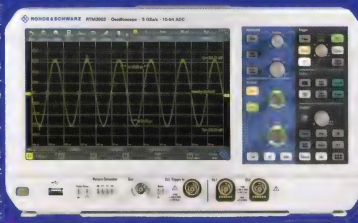
The sale includes fully optioned spectrum analysers, power supplies, power analysers and oscilloscopes.

More information can be found on the web at **www.rohde-schwarz.com/au/featured-topics/value-instruments/value-instruments_230648.html** or on the Rohde & Schwarz Australia LinkedIn page at **www.linkedin.com/showcase/r&s-australia-test-and-measurement**



SERVICEMAN'S LOG

Dave Thompson

Fixing a "Cheap as" set of cans

While there's a huge range of cheap electronics available online, some of it really is 'cheap'. It's unfortunately not uncommon to receive goods different to what you paid for. Sometimes I wonder whether the time lost dealing with all this is worth the money saved.

I don't know about the rest of you, but I've made good use of cheap Chinese imported goods. I discovered AliExpress many years ago but I was initially hesitant to send any money off in that direction.

After all, early incarnations of Alibaba and similar B2B (business-to-business) sites were ill-policed and well-known as a scammers' paradise. But after I dipped my toe into the warm waters of low-cost electronics, I became comfortable with the idea and by now, I've ended up throwing a lot of cash eastwards.

I have now completed many hundreds of trades, often finding and purchasing components I haven't been able to find locally for ages. For the most part, it has been a painless experience. These days especially, with escrow-type payments and a credible seller feedback system, buying something from any of China's online merchant sites is simple and (mostly) without fear of being burned.

This is not to say everything always goes smoothly; once, after much toing and fro-ing with a vendor via the messaging system, I ordered a relatively expensive circuit board for a client's dead flat-screen TV. Instead, what turned up in the post was a very cheap Fitbit-style device worth a fraction of the cost of the PCB.

When I went back to the vendor to get an explanation, I got no answer, despite repeated and increasingly-pointed messages. Eventually, I decided that he must be purposely trying to exceed the then-30-day buyer-protection period, after which he'd be paid regardless, unless I lodged a complaint first.

The guy eventually did reply, claiming the error had been made at China Post and was thus out of his hands and I should get hold of them to sort it out. He also requested I mark the goods received and accepted so payment could be made.

Since I didn't come down in the last shower, I declined his generous offer and told him that unless he sent me the board I'd ordered, I would lodge a complaint, apply for a full refund and give negative feedback, something most vendors try to avoid at (almost) any cost.

After hearing nothing more for a week, I went ahead and filed a dispute and got my money back. Unfortunately, he was the only vendor I could find selling that particular PCB, so that was the end of that. However, this sort of event is quite rare, and I've only had to deal with a handful of disputes over the years.

Caveat emptor

For the most part, the products depicted on the site are as-described, and aside from the odd purchase taking over six weeks to arrive, most transactions are hassle-free, and everyone comes away happy. That said, B2B sites can still be a trap for the unwary. A certain amount of awareness and a healthy dollop of common sense goes a long way to avoiding potential embarrassment.

In the early days, I learned the hard way. For example, there were many listings for 'iPhones' priced considerably below what you'd expect to pay here. The 'phones certainly looked like iPhones, complete with the Apple logo and product information stencilled on the case, and no wonder; the images were those of actual iPhones.

But in reality, the item for sale was a locally-produced clone, and not a very good one at that. The phone I received was nothing like the one in the photo. Not only was it nowhere near as well-made as a real iPhone, but it also was low-spec, didn't run iOS (it used some version of Android) and couldn't be used with an Apple account, run iTunes or use any other apps from the Apple Store.

I ended up giving it away to a visitor to the workshop who expressed interest in it; I think he threw it in the bin not long after that. Thankfully, this type of deception is now rare, and dodgy vendors are quickly reported and removed. It still pays to be cautious though, especially when something seems "too good to be true".

Those new to these sites might think some of the advertised products are fantastic bargains, but more experienced visitors know that most of the time genuine big-name products are not that much cheaper (if at all) than those sold by local retailers or Western online vendors. At least here we are protected by consumer laws and warranties, which is not always the case with foreign purchases.

Even servicemen sometimes fall into traps

A while back I was in the market for

For those not in the trade, "cans" is a common nickname for headphones.

Items Covered This Month

- Headphones in one ear, regret in another
- Digital photo frame repair
- A self-discharging Suzuki Vitara

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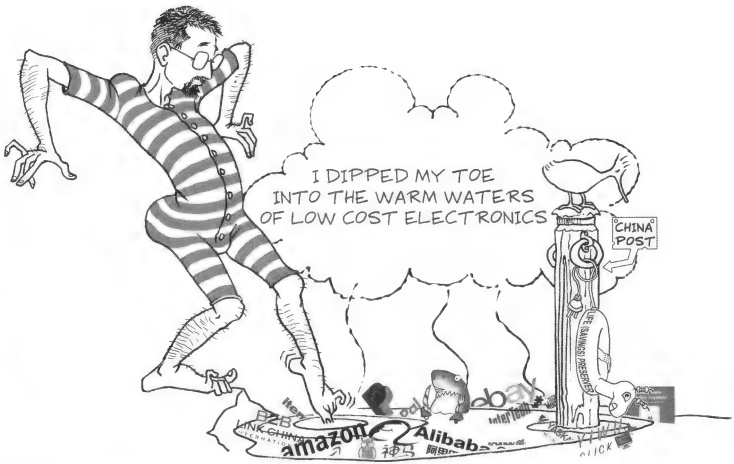


a new set of headphones, and I purchased a pair of Sony wireless Bluetooth "over-ear" style headphones from a local big-box store. I couldn't wait to get home and try them out, but was extremely disappointed when I plugged them in and discovered that while they were well-made (as with most Sony products), and comfortable, the sound quality was abysmal.

I was annoyed with myself more than anything; the only store who carried this particular model of headphones didn't have a "try-before-you-buy" stand like many others (policy, they said), so I'd thrown caution to the wind and relied on price-point, brand recognition and faith that being Sony, they should be good quality.

Before I discovered the benefits of decent earplugs, I'd had my hearing pounded by years of exposure to power tools, high-octane model-aircraft racing engines, playing in bands and attending too many rock concerts. But I can still differentiate between what sounds good and what doesn't, especially when using headphones.

So I took them back to the store and had a stand-up argument with the teen-aged 'manager' who insisted that either I hadn't charged the battery enough or that I expected too much fidelity from a Bluetooth wireless system. Apparently, this was no basis for returning them.

I politely informed the guy that the battery was well charged and that the Bluetooth earbud headphones I bought from China for a few dollars to use with my mobile phone had excellent fidelity and outperformed these expensive Sony 'studio' 'phones by a wide margin.

I stood my ground and asked to try out another set of the same model headphones, in case the originals were faulty, but the manager informed me Sony wouldn't allow them to open a sealed box without a sale, so I demanded a refund instead.

While I eventually got my money back, the store made me jump through hoops and wait for more than a fortnight while they sent the headphones back for 'testing' and got the warranty sorted.

My complaints that this whole process broke our consumer-guarantee laws fell on deaf ears (LOL), but I was vindicated a few months later when I read reports that this chain of stores had been prosecuted, found guilty and substantially fined for dozens of similar breaches of consumer regulations. I certainly won't be shopping there ever again.

It's no wonder then that I (and others) increasingly shop online, often from overseas vendors. Not only do I avoid being patronised, but I also cut out the greedy middle-man altogether, and this makes my hard-earned dollar go further.

However, the government has caught on – most likely due to lobbying by campaign-funding, cry-baby big-box retailers who constantly whinge about an 'uneven playing field', despite them having gouged consumers blind for years – and are intent on

Servicing Stories Wanted

Do you have any good servicing stories that you would like to share in The Serviceman column? If so, why not send those stories in to us?

We pay for all contributions published but please note that your material must be original. Send your contribution by email to: editor@siliconchip.com.au

Please be sure to include your full name and address details.

I WAS VINDICATED WHEN THIS CHAIN WAS PROSECUTED, FOUND GUILTY & SUBSTANTIALLY FINED FOR DOZENS OF SIMILAR BREACHES OF CONSUMER REGULATIONS

introducing an "Amazon tax", like in Australia.

This will add GST and other local taxes onto products valued at less than $1000 purchased from overseas (products valued $1000 or more are already heavily taxed), though I'm not sure how they are going to coerce Amazon, Bangood or AliExpress into collecting Kiwi taxes.

I guess that these online sellers will merely do what they've done in other countries whose über-greedy governments slap taxes on small overseas purchases and either stop selling here altogether or limit what products are sold here. Excellent!

Going on a shopping spree

In the meantime, I'm buying all I can. Lots of cheapo modules like Arduinos and accessories, valves, amplifiers, guitar parts, shoes, clothes; you name it, I've bought it!

One of these purchases was a pair of headphones. The listing on AliExpress showcased some Bingle-branded wired models (with USB and 3.5mm audio jack connectors) that ticked all my purchasing boxes.

They look very similar to those (typically) green 'aviator' or military-style noise-excluding headphones you often see pilots wearing. As I'd tested or repaired hundreds of 'real' versions during my time at the airline, they have the benefit of familiarity. They also possess a certain retro-cool.

But all was not as it seemed; while the 'phones in the product images were almost certainly the genuine Bingle versions, the ones that arrived here almost certainly weren't.

They looked similar, but the build-quality said otherwise. The seller had also offered to ship the product without retail packaging because the increased size makes postage more expensive. More likely the product isn't genuine and the packaging is non-existent or a plain white box.

While some sites offer the product in retail packaging, the cost is usually higher, perhaps to dissuade buyers. Not all sellers will be hawking fake products using this ploy, but due diligence is recommended!

In this case, I chose to get the packaging, just in case I wanted to re-sell the 'phones at some point and duly paid more for the privilege. When the 'phones arrived, the typical yellow tape and a single sheet of wafer-thin bubble-wrap packaging hadn't prevented the box from being bashed in transit to roughly the shape of the 'phones inside anyway. Lesson learned.

While they weren't the real thing, they did at least sound quite good and were reasonably comfortable to wear. Nonetheless, I had much remorse, as well as annoyance at myself for falling for the dodge.

I filed a dispute but only asked for half the purchase price back. For better or worse I had a set of 'phones, and returning them would have cost me more than all this was worth – a fact I'm sure many vendors are well-aware of. I left feedback accordingly, leaving no doubt about the authenticity of the product and put it all down to experience.

I note that these 'phones are no longer being sold on AliExpress where once they were all over this site. I wonder why...

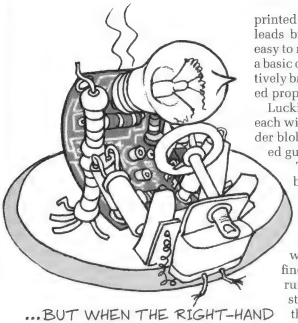
And this was how things remained until one day the 'phones stopped working on one side. Actually, the detachable boom mic stopped working first, almost from day one, but since I wasn't using it and had removed it anyway, I wasn't too bothered. But when the right-hand driver suddenly stopped, it was time to roll up my sleeves and break out the screwdriver set.

Time for a repair

Some headphones I've worked on in the past have been a real pain to tear down, being tightly clipped together with breakaway plastic tabs. Getting them open is semi-destructive, and they have to be glued back together. Surprisingly, these headphones were all screwed together, and with standard fasteners – none of those ridiculous anti-tamper things to hinder my progress – so disassembly was a doddle.

The way into the headphones is typical of most; remove the cushioned earpads by working around the edge of the earpad mounts, gently stretching the material clear. Once off, the screws holding the mounts are revealed; there were four on each side to take out.

To make things easier, I removed the thumbscrew-style height adjusters sitting above each pod (or "can") and released them from the headband assembly. The two cans were still connected by an audio cable, which runs through the hollow headband padding, but after removing the stiff metal part of the headband, I could at least flex everything and work on each side without



the other getting in the way.

I began with the left-hand pod, as this is where the main audio cable enters and any electronics should be located inside it.

After removing the outer earpiece ring, there were three longer screws underneath holding the two shells of the can together. Once the screws were out, the two halves easily separated. Inside was a sizeable PCB containing what I assumed to be an amplifier and a USB decoder.

The 3m long main cable enters the bottom of the pod through a plastic strain-reliever and sports USB and 3.5mm jacks (one 3.5mm stereo jack for sound input and another mono jack for microphone output) at the far end. A second, much thinner cable exits the top of the can through a grommet and heads off through the headband to the other pod.

The shielded main cable contains eight tiny wires, and the thinner cable has three, all colour-coded and terminated to their respective solder pads on the PCB. Or perhaps I should say, they should be terminated; I could see three wires floating happily in the breeze, while the others looked to be tack-glued to the PCB with large, dull solder blobs.

Whoever put this together should go back to soldering school. It was a wonder it worked at all!

Before doing anything, I had to figure out which wire went where on the PCB. As is typical on cheap electronics, there was no information screen printed onto the board. Usually, if leads break free, they are relatively easy to match using a microscope and a basic comparison with their distinctively broken ends; if just not connected properly, this can be a bit trickier.

Luckily, in this case, I could match each wire to an impression in the solder blobs enough to make an educated guess.

The type of wire used in the cables is prevalent in audio gear. Each multi-stranded wire is very fine and well-insulated, but not by an obvious plastic coating like other types of wire. Each wire also has very fine cotton or synthetic threads running through it, likely for strain relief, which along with the insulation material makes soldering it a real challenge.

Even with a decent amount of heat, solder just beads and runs off. No wonder it was just globbed together at the sweatshop, er, I mean factory.

In the past, I've had to burn the insulation off to be able to solder it. In the early days, I used a match; now, I use a small gas torch, the kind used for jewellery or micro-welding. A brief touch to the end of the wire causes the thread and insulation to instantly burn off. A quick pinch with a damp sponge removes any crispy remains, leaving shiny wire behind.

While solder sticks to this cleaned surface, I also use a touch of flux to help it 'sweat' through.

While I was at it, I also re-soldered the other connections, prepping and cleaning wires and PCB pads before tinning them all with fresh solder. It was simply a matter of a quick touch with the iron to re-connect everything and a sound-check confirmed I had audio in both cans and a working microphone.

Reassembly was as easy and pulling them apart, and I still use these 'phones today. Not exactly Bingles, but OK for cheap Chinese imports.

Digital photo frame repair

B. P., of Dundathu, Qld is another person who is willing to put in a little bit of effort to fix a device, even a fairly cheap one, rather than throwing it away and buying a new one. And as he says, sometimes the faulty component is obvious and the repair is not too difficult. You just need to be willing to have a go...

A few years ago, we bought a used 15-inch digital photo frame on Gumtree. Initially, I had some problems setting up this unit, as it didn't want to display the photos on the SD card and reverted to showing the stock photos on the inbuilt memory.

I solved this by deleting the stock photos and putting our photos on the inbuilt memory. It then performed well for a few years.

But recently, my wife commented that she was having problems getting the photos to display and she would need to power the unit on and off several times before it started working. This went on for around a week; then it just stopped working altogether.

I observed that it would initially show the splash screen for around one second, then a blank screen. I tried a different plugpack power supply in case that was faulty, but nothing changed.

So the unit itself was faulty and I suspected that it might be a dud capacitor. I started opening it up by removing the 12 #1 Philips head screws from the back cover, which gave access to the inside. I then disconnected four plugs so I could remove the back completely and inspect the circuit boards.

It didn't take long to spot the faulty electrolytic capacitor on the inverter board. The bung had been pushed out the bottom of the 220µF 25V unit. That was apparently the problem, and I thought it would be an easy fix.

Usually, I would use a salvaged capacitor for repairs like this, but because this capacitor was lying down, I would need to use a new capacitor with long leads. Because of the limited space inside the unit and the fact that the inverter board has a plastic cover over it, I couldn't mount the replacement vertically.

With a new capacitor fitted, I re-installed the inverter board and went to re-connect the four plugs that I had disconnected earlier. But when I went to re-connect the 20-pin plug on the video board, but I ran into a problem.

Typically, there is one pin missing on the header and a blank in the plug, so you can't insert it backwards, but in this case, there was not and I had not paid any attention to the orientation of the plug when I'd removed it. Being mindful that if I put the plug on the wrong way, I could damage something, I had a closer look at the PCB and the plug.

Luckily, on closer inspection, it was obvious which way the plug went on. The PCB was marked +3.3V at one end of the header, and the 20-pin plug had two red wires at one end. The other end had two holes with no wires in them. So clearly, the end of the plug with the two red wires went to the end of the header that was marked +3.3V on the PCB.

Because of the missing wires, it seems that no damage would have occurred if it was reversed anyway, it just wouldn't have worked.

Before permanently attaching the back, I gave the unit a quick test to make sure that it was working. On connecting it up and turning on the switch, I could see the splash screen very faintly, indicating that the backlighting was not operating. I then realised that one of the plugs for the backlighting that I had just re-connected had come out, so I plugged it back in and tried again.

This time, the screen came up brightly, indicating that the unit was now working. I turned it off and disconnected the plugpack and replaced the 12 screws that secure the unit together, as well as refitting the stand. I could now return the unit to use again after a successful repair.

My wife and I both noticed that the display was now a much better colour than it had been previously. I concluded that as the old capacitor was failing, that the voltage for the backlighting must have dropped, therefore resulting in a duller than normal backlight and therefore a slightly washed-out picture.

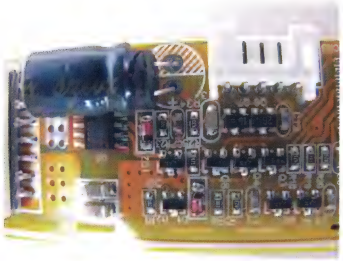
The replacement cost of a brand new unit equivalent to this one is over $100, so for 45 cents and a bit of time, this unit was saved from the scrap heap and will live on in its second life.

A Suzuki Vitara and its discharging battery

S. Z., of Queanbeyan, NSW had the maddening experience of not being able to track down the source of an intermittent fault. Most of us know what that's like; it seems that the problem will occur any time except for when you are trying to track down its cause! He found it in the end, although it took a great deal of luck...

After a long period of being very kind to batteries (some lasting many, many years), my Suzuki Vitara recently started killing them. It began on the morning of the Australia Day long weekend. We were about to leave for a big trip to Morton National Park to tackle Monkey Gum Fire Tail when the car refused to start. The battery was dead flat. That's never happened before.

At the time, I surmised it was just



because I had been "showing off" the newly installed winch to the missus the night before, and maybe I'd used up more charge than I'd thought. I managed to charge it up enough to start it, but just to be sure, I bought a new battery that morning and installed it.

The trip was a success, although it was tough on the vehicle. Minor body damage will remain forever as a reminder to never tackle that track again.

A few days later, when I tried to start the car for the commute to work, the new battery was again dead flat. The battery was also quite warm to the touch. The charger refused even to try charging the new battery. Luckily, I'd kept the old one, and it was on charge. I put the old battery back in and it started the car easily.

I thought that I'd simply been sold a dud battery. When I took it to the place I got it, they declared that it had a shorted cell and replaced it for me, although I didn't put it in the car straight away.

The very next morning when I attempted to start the car, it was again dead. The battery was again warm to the touch. This time it had ejected a lot of electrolyte into the engine bay too! I now thought that the car might have a massive "phantom load" that was utterly discharging the battery overnight.

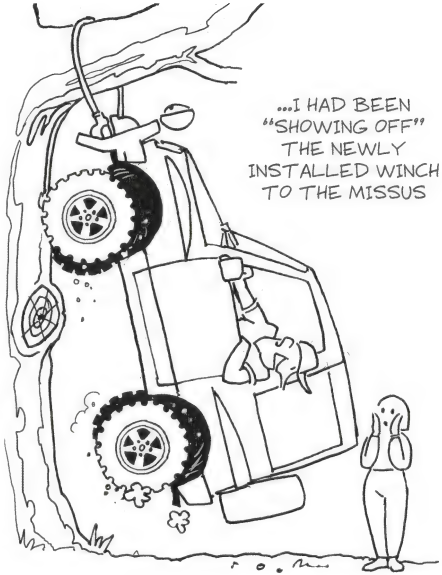
Over the years, I've added a couple of extra power feeds directly from the battery terminals, including one for radio equipment and one for the new winch.

As the winch was the latest change I had made, I suspected it might have caused this problem. Just to be safe, I disconnected everything that wasn't essential to running the car.

I removed the now-dead old battery and put the second new battery in and drove to work – late and somewhat confused.

During my lunch break, I started looking for this phantom load. I used an ammeter to measure the current flowing through the extra power wires I'd installed with the vehicle switched off, but couldn't find any. I then connected the ammeter between the positive terminal of the battery and the battery connector itself and got a reading of about 35mA. That seemed normal.

So I was stumped. Two batteries failed in the same way, yet I couldn't find any phantom loads. I spent the next couple of days doing further current and resistance measurements



while jiggling cables and connectors. I also spent time checking the alternator voltage regulation as maybe it was overcharging batteries and causing damage. I was pretty puzzled all as everything measured as being OK.

Maybe I'd just gotten unlucky twice, but I started disconnecting the negative side of the battery terminal every night just to be sure.

A week after all this began, I had some spare time but was out of ideas, so had another look under the bonnet. I remembered that the last battery event had spewed acid everywhere, so I decided to hose out the engine bay. It got a good wash, especially near the battery, where most of the acid was. Then I heard the distinct sound of rapidly boiling water, similar to frying.

This noise directed me to the fault like a beacon. A single wire, part of a larger wire loom, had been rubbing against the metal of the battery holder, probably for years, and had finally scraped through the insulation.

This wire is obviously connected to the battery positive terminal and is situated in such a way that the slightest bump or vibration could allow it to short against the grounded frame, or remove the short. So that's why I couldn't find it earlier.

This would have driven me mad. Being well hidden from view means that I would never have seen the bare wire if the sound hadn't alerted me.

The repair was simple: some self-amalgamating tape for the wire, and an extra physical barrier material wrapped around the entire wire loom.

Intermittent faults are the worst, and are particularly soul-destroying when it means you can't trust something you need to use every day. This time, I was lucky! SC

This is one of those gadgets which you have always needed – but until now, never realised it! It uses the highly accurate time signals embedded in a GPS signal to display your car's speed – almost certainly with much more accuracy than your speedo. It displays the exact time – without you having to set it. And last – but by no means least – it automatically adjusts your car radio/stereo volume to a comfortable level which suits the speed you're travelling at as well as noise in the car. It's cheap and easy to build . . .

GPS FINESAVER

. . . PLUS!

- *Very* Accurate Speedo
- *Very* Accurate Clock
- *Automatic* Car Audio Volume Adjustment

by Tim Blythman

If you have any doubts about the accuracy of your car's inbuilt speedo (and you should!), then this little circuit is about to become your best friend!

Speedometers can (legally) give readings which *overstate* your true speed by as much as (10% + 4km/h) high!

That can leave you with a difficult decision: be overtaken by just about everybody, or speed up and risk going over the speed limit, as you don't know exactly how fast you are going.

By the way, if you drive an older (<2006) car its speedo could be worse – much worse! The old rule simply said ±10% – so if you're innocently driving along with your speedo showing 100km/h (the speed limit), you could actually be doing 110km/h – and you won't know about it until you start seeing flashes of red and blue!

But with a clear view of the sky, GPS speed readings are typically accurate to well within 1km/h. So it's worth building this project just for that function alone.

But wait, there's more!

It's also a *very* accurate clock. GPS provides not only an accurate determination of your speed and position, but the (exact) current time as well.

This is converted from UTC to your local time and it is also shown on the display. All that you need to do when you set up the unit is enter your local timezone offset.

Having accurate time also solves yet another common driving problem: your dashboard clock says it's 4:01pm... Phew! Just missed that school zone 40km/h limit. So you sail through at the "normal" 60km/h speed limit.

Or *did* you just miss it? Is it actually 3:59pm and the 40km/h school zone limit still applies? FLASH! Uh-oh: maybe your clock is ever-so-slightly out?

It's better to know for sure, and GPS time is accurate to

the millisecond. (That, incidentally, is also how school time zones know when to book you and when not to).

I already have a sat-nav!

Not like this, you don't. In-built (ie, OEM-fitted) sat-nav systems are great – but we don't know of **any** which display instantaneous speed, as this one does. That's because the manufacturers want to avoid a legal "stoush" when the sat-nav and speedo showed different readings, which they almost invariably will.

(On the other hand, aftermarket sat-nav units almost invariably display instantaneous speed, which is why you'll see many cars with both an in-dash and an on-dash GPS).

But wait, there's even more!

When you are driving in traffic which is continually speeding up and slowing down, do you continually have to nudge the volume of your radio or car stereo up and down to maintain a comfortable listening level above the road noise? This clever little device will do that for you, without you having to take your eyes off the road!

Many newer (luxury?) cars have this feature built in – it's called SVC or speed-sensitve volume control. Build this project and your old jallopy can have this feature too!

You can see a typical display in the photo opposite.

The bar graph at the bottom shows the volume adjustment which is currently being applied to audio signals passing through the unit. Refer to Fig.4 to get an idea of how the volume varies with speed. We'll cover that in more detail later.

Making the audio connections

Looking at the volume control function first, it has a 3.5mm stereo input and output socket, for compactness. The way you use the GPS Volume Control will depend on the setup you have.

You will need to be able to insert the GPS Volume Control into the audio signal path to give it control of the volume.

It is ideally suited to taking audio from a portable audio source such as an MP3 player or mobile phone with a 3.5mm output socket. If you have an arrangement where you connect a mobile phone into the auxiliary input on your radio 'head unit', then this lead can now be used to connect the GPS Volume Control to the head unit.

Then you will merely need another auxiliary lead to connect your existing audio source into the input of the GPS Volume Control, and it will control the volume of the audio passing through it.

Alternatively, if you have a head unit feeding a line level signal into a dedicated amplifier, then the GPS Volume Control can be connected between the head unit and amplifier. Many aftermarket head units have RCA 'preout' output sockets at the back. In this case, you can use 2xRCA to 3.5mm jack plug leads to make the connections.

If you have a standard DIN-size radio in your car but no preouts and/or no separate amplifier, the easiest way to install this device seamlessly may be to replace your radio with one that does have preouts and wire up a separate amplifier to drive the vehicle's inbuilt speakers. You can then easily connect this unit between those two devices.

Unfortunately, if you have a single dedicated head unit with integrated amplifier, there's usually no easy way to tap into the audio path to alter its volume. Your only real option is to open the unit up, find the tracks feeding the signals into the power amplifier section, cut these, then solder the inner conductor of shielded wires to each end of these tracks, with the shields going to a nearby ground point.

These wires can then be soldered to 3.5mm stereo plugs, one for the outputs of the preamp and one for the inputs to the amplifier, which should then be routed out of a hole at the rear of the unit (drill one if necessary), which can then be plugged into the GPS Volume Control sockets.

Each head unit will route its audio signals differently so we can't give you much guidance in finding them, except to suggest that you look for the audio amplifier chips/transistors, which will probably have heatsinks, and try to find the signal tracks leading to them.

You will need a scope or audio probe to have much chance of figuring out which tracks carry the audio signals. This is not a job for the faint-hearted or inexperienced.

Features

- **Powered from 12V DC (eg, vehicle supply) or USB 5V DC**
- **Automatic GPS speed-based volume control**
- **GPS speed display**
- **Shows local time derived from GPS**
- **Volume control range: 0-200%**
- **Stylish, slimline laser-cut case**
- **Blue OLED display matches many car consoles**
- **Display brightness adjustment**
- **Automatic display dimming can be easily added**

How it works

Unsurprisingly, the GPS Volume Control is based around a microcontroller. The circuit diagram is shown in Fig.1. We're using a 'lowly' PIC16F1455.

While this is a low-cost device, it does everything we need and comes in a compact 14-pin DIL package.

You might remember that we used this chip for the May 2017 Microbridge (siliconchip.com.au/Article/10648) and Micromite V2 BackPack (siliconchip.com.au/Article/10652) articles. It has USB support, but we aren't using that in this project.

Let's start by looking at the audio processing, as that is one of the main aspects of this device.

The stereo audio signal is applied to CON2, a 3.5mm socket. 100kΩ resistors provide a DC bias to ground while 1kΩ series resistors protect the rest of the circuit from excessive voltages.

The signal is then AC-coupled to digital potentiometer IC2 via 1µF non-polarised capacitors, with the digital pot signals DC-biased to a 2.5V half supply rail via 22kΩ resistors.

IC2 is an MCP4251 dual 5kΩ digital potentiometer. The P0A/P0B and P1A/P1B terminals connect to either end of the 'track' of the internal potentiometers, while P0W and P1W are the digitally controlled 'wipers' which move along those 'tracks'.

The audio signals are applied to the "A" track ends while the "B" track ends are connected directly to the 2.5V reference rail. So with the 'wiper' at the "A" end, the signal amplitude is pretty much the same as the original, and when it is at the "B" end, the signal is heavily attenuated.

Intermediate positions give different amounts of attenuation.

There is a little extra attenuation in the signal due to the 1kΩ series protection resistors, so the maximum output signal is about 80% of full amplitude while the minimum is around 1%.

The signals from the wipers go directly to the non-inverting inputs (pins 3 & 5) of dual rail-to-rail op amp IC3 (LM6482AIN). The two channels have a gain of around three, set by the 10kΩ and 5.1kΩ feedback resistors. As well as providing gain, this op amp provides low output impedances.

Taking this gain into account, the total gain across the analog section of the circuit is just over two. Given that the digital potentiometers power up with their wipers set at their mid-points, the default gain is slightly over unity.

The output from IC3 is AC-coupled by two more 1µF capacitors. The op amp is isolated from any output capacitance by a pair of 100Ω resistors. The 22kΩ resistors re-bias the output signals near 0V. These signals are fed to another 3.5mm jack socket, CON3.

GPS data

The GPS module is connected to CON7 and runs from the same 5V rail as the ICs in this circuit. It generates position, speed and time data once per second and this is sent to microcontroller IC1 in NMEA1803 format. This signal goes to the hardware UART serial input on pin 5.

We used an SKM53-based module for our prototype but the VK2828U7G5LF modules (or revised -U8G5LF versions) available from the SILICON CHIP ONLINE SHOP also work fine (see **siliconchip.com.au/Shop/7/3362**).

IC1 processes the serial stream and extracts time, speed and validity data from the RMC 'sentence', which it expects to receive at 9600 baud. That is the default for many GPS modules, including those mentioned above.

Note that the "RM" in RMC stands for "recommended minimum", meaning that all NMEA-compatible GPS receivers will generate this data. Typical RMC data is shown in Fig.2.

IC1's system clock is generated internally and runs at 48MHz, with a 12MHz instruction clock.

Once IC1 gets valid data, it updates the display on the OLED screen using an I^2C serial bus from pins 7 (SCL, clock) and 8 (SDA, data). This display shows your current speed, in large digits.

It also calculates the new potentiometer setting for the appropriate volume, based on your speed, and sends a command to the digital pot to update its current 'position'. This is sent over IC1's SPI serial bus to IC2 via pins 9 (SDI - data), 10 (SCK - clock) and 6 ($\overline{CS}$ - chip select).

The three onboard tactile pushbuttons are connected between pins 2, 12 & 13 of IC1 and ground. These pins are configured as digital inputs and each has a 10kΩ pull-up resistor to the 5V rail.

So usually these inputs are held high but if a button is pressed, that input goes low and IC1 detects this and takes the appropriate action.

Why do you need to turn the volume up when you're moving faster?

Most sources of noise in a vehicle vary depending upon your speed.

The major sources vary from vehicle to vehicle, but it typically consists of a mix of road (tyre) noise, engine noise and wind noise.

Engine noise can be further broken up into induction noise, mechanical noise, transmission noise and exhaust noise.

Road noise is the sound that your tyres make as they rotate and distort under the weight of the vehicle. This varies based on speed, road surface, conditions (eg, water on the road) and tyre type/condition.

It's attenuated by the vehicle's sound-proofing, but some vehicles have much better soundproofing than others.

The only easy way to reduce this is to swap out your tyres for quieter ones, but there is usually a compromise between quietness, grip and cost. So if you want quiet tyres with lots of grip, they will probably be costly. And high-performance tyres are usually noisy even though they are expensive.

Engine noise varies by many different parameters. There is very little of this in an electric car – usually just a whine.

But petrol and diesel engines can vary from whisper quiet to deafening. This varies to some extent based on load, which is related to how fast you are going, as well as whether you're going up or down a hill and whether you are accelerating, cruising or coasting.

Engine noise consists primarily of induction noise (air going into the engine) and mechanical noise (fuel injectors, valves, gears). Combustion noise is normally muffled significantly by the water jacket.

Vehicles with forced induction (turbo- or supercharged) typically have less induction noise, since the compressor muffles it. But modern direct-injection petrol or diesel engines typically have very audible injectors, while older engines may have more valve-train noise.

Exhaust noise depends on the type of engine, load conditions and exhaust system type and condition. Exhausts in poor condition or high-performance exhausts will let a lot more noise through. Turbocharged cars may have less exhaust noise since the turbine reduces exhaust pressure pulses.

Wind noise is typically only heard at higher speeds and usually only if the other sources of noise are low (ie, a well-insulated car with a quiet engine cruising at speed). You may hear whistles or buffeting.

This varies depending on the aerodynamic design and anything attached to the outside of the vehicle, such as a roof rar' rain shields, bull bar and so on.

Power supply

DC power is fed into either CON1, a 2-way header or at CON6, a mini-USB socket. CON1 can be connected to a vehicle's nominally 12V DC supply (varying over approximately 11-14.5V) and this feeds 5V regulator REG1 via D1, a schottky diode used for reverse polarity protection. If USB power is applied to CON6, this bypasses REG1 and powers the circuit directly.

Only one of these power sources should be connected at any time. The 5V rail powers IC1, IC2, IC3, the OLED screen, the GPS module and is also used to derive the 2.5V half supply rail via two 10kΩ resistors and a 220µF filter

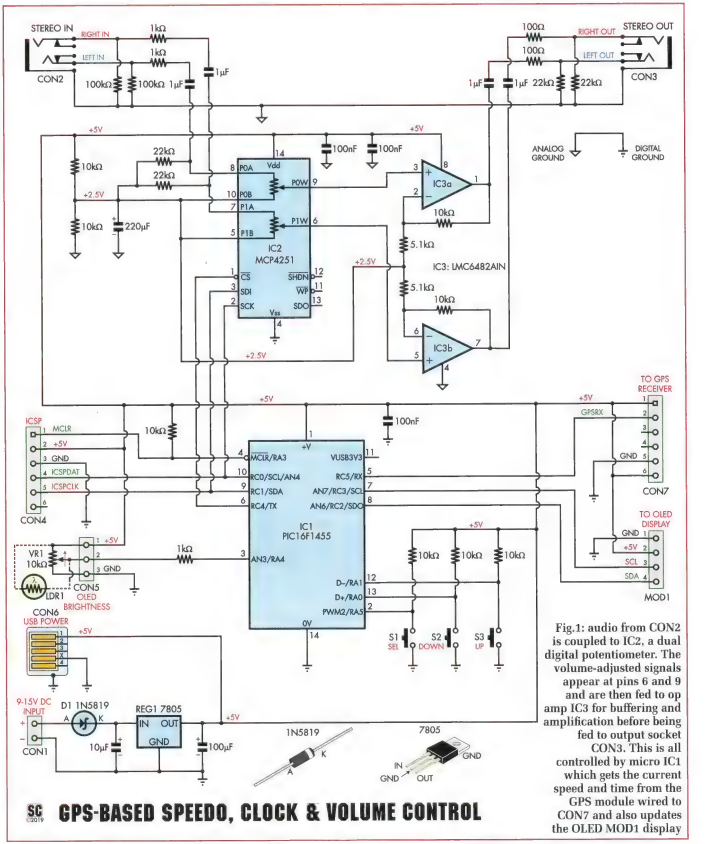


Fig.1: audio from CON2 is coupled to IC2, a dual digital potentiometer. The volume-adjusted signals appear at pins 6 and 9 and are then fed to op amp IC3 for buffering and amplification before being fed to output socket CON3. This is all controlled by micro IC1 which gets the current speed and time from the GPS module wired to CON7 and also updates the OLED MOD1 display

SC 102019

GPS-BASED SPEEDO, CLOCK & VOLUME CONTROL

Fig.2: the GPS module produces a serial data stream consisting of 'sentences' which carry GPS information. The 'RMC' sentence contains all the information we need; the time, speed (in knots) and whether a valid fix has been achieved. Note that in this case, the date is out by around 19 years as this module suffers from the GPS week roll-over bug, but it still gives valid time and speed data.

capacitor.

Serial communications

As mentioned above, the GPS signal, OLED screen control and digital potentiometer control are transmitted over three different types of serial bus: UART, I²C and SPI respectively.

To avoid conflicts between the various hardware peripheral modules and to provide maximum pin flexibility, the UART interface is implemented in hardware while the I²C and SPI buses are software-driven ('bit banged').

The control of the digital potentiometer is straightforward; we need only transmit a six-bit command followed by a ten-bit potentiometer value to update the position of one of the potentiometers. For simplicity, this sixteen-bit command is sent as two eight-bit values, as we don't need the full precision of the potentiometers.

The value sent is proportional to the wiper position and thus the final volume. Both channels are set to the same value to maintain stereo balance.

The display module, MOD1, incorporates an SH1106 display controller and a 128x64 OLED panel, as well as I2C pull-up resistors and a regulator to supply 3.3V to the SH1106. The I2C interface does not need level conversion as the microcontroller only needs to pull the I²C control lines down to GND; the module's onboard pull-ups bring them back up to 3.3V when the micro releases them.

IC1 initialises MOD1 during its startup sequence and continues to update it to display the information that is needed. There are two main screens; one has the speed, time, current volume and GPS signal status. The second screen shows some settings which can be changed.

The one remaining pin on IC1 is an analog input and has been broken out to a three pin header, CON5. This can be used to adjust the display brightness manually using a trimpot.

But you could instead connect a voltage divider comprising a fixed resistor and a light-dependent resistor (LDR) to provide automatic brightness control.

Microcontroller IC1 is configured with an internal timer (Timer1) which triggers an interrupt around 22 times per second. This is used to smoothly ramp the volume as well as keep a check on how long it has been since a valid GPS sentence has been received. This prevents stale data from being used for calculations.

Laser-cut case

We've designed a slimline laser-cut case specifically for this project, so the completed unit is only about 20mm thick. The top panel is simple, with just the display and three buttons visible. Access to the power, audio and header for the GPS are through the sides, as is the trimpot for brightness adjustment.

Sourcing the OLED screen

There are various generic OLED modules available in different sizes; we are using a 1.3in variant, although 0.96in versions are also available with a similar I²C interface.

Some OLED modules have a different pinout to the one we used, so check this when you are ordering yours. Ours has four pins, which are from left to right: GND, V_{CC}, SCL and SDA.

Some OLED modules also use the SSD1306 display controller, which uses a superset of the commands used by the SH1106. The software has been designed to be compatible with both display controllers.

Construction

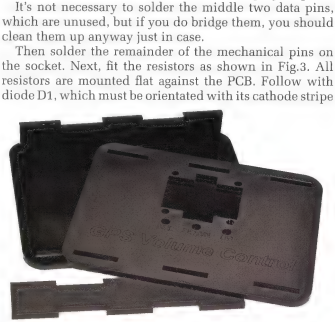
Use the PCB overlay diagram, Fig.3, and matching photo, as a guide to assembling the board. The project is built on a double-sided PCB coded 01104191 which measures 92mm x 69mm. As mentioned earlier, it is housed in a custom-made acrylic case which results in a compact package, only about 20mm thick.

The most challenging part to solder is the SMD mini-USB socket, so if you plan to use this, solder this first. Locate the socket using the lugs on its underside and tack one of the mounting tabs in place.

Check that the two power pins are correctly aligned and then solder them to their pads. We have made the solder mask openings slightly larger so that you don't need to get your iron in so close (which would risk bridging the pins).

It's not necessary to solder the middle two data pins, which are unused, but if you do bridge them, you should clean them up anyway just in case.

Then solder the remainder of the mechanical pins on the socket. Next, fit the resistors as shown in Fig.3. All resistors are mounted flat against the PCB. Follow with diode D1, which must be orientated with its cathode stripe



The four components of the laser-cut acrylic case. We've made the matte side the outside to minimise reflections.

aligned as shown.

As you continue construction, keep in mind that the front panel will be mounted around 10.5mm above the top of the PCB, so taller components (eg, electrolytic capacitors) need to be laid on their sides. As you proceed with assembly, check that all components are mounted flush so that they aren't higher than necessary.

Fit the three ICs next. Although you could use sockets, we would not recommend them for IC2 and IC3, as they may affect the audio signal integrity. Make sure the ICs are orientated as shown in Fig.3.

REG1 is mounted with its tab against the PCB. We suggest that you attach it to the board using a machine screw and nut before soldering its pins. Due to minimal clearance behind the PCB, put the head of the screw behind the PCB and attach the nut from above. Note that REG1 and D1 can be omitted if you don't plan to run the unit from a 12V supply.

Next, fit the MKT and ceramic capacitors where shown, followed by the electrolytic capacitors, which must be laid over for the case to fit later. Only the electrolytic capacitors are polarised. Make sure that the longer leads go into the pads marked "+" on the PCB.

Now mount 3.5mm sockets CON2 and CON3. Some types can be quite a firm fit on the PCB, so check that they are pushed all the way down before soldering their pins. They are keyed and will only fit one way.

Next install CON4, the ICSP header. If you have a pre-programmed PIC or can program the PIC before installation, you can leave it off. We suggest using a right-angle header, but a typical straight header is only 9mm tall and so should also fit.

Then attach the connector for the GPS module (CON7). We used a right-angle male header and interfaced to the GPS module using jumper wires so that we could easily detach it. We then wrapped the GPS module in heatshrink so that it can be placed in a spot that has a good view of the sky. You could solder wires from the GPS module directly to CON7 if you prefer.

If you're fitting a multi-turn trimpot for manual screen brightness adjustment, bend its leads by 90° and solder it to the pads for CON5. Although it will overhang the PCB, the case is large enough to protect it.

To use an LDR for automatic brightness control, we suggest that you fit a 1MΩ multi-turn trimpot instead, then solder a 10kΩ LDR between the middle pin and the one marked "5V". Later, when you're putting the whole thing in a case, you can bend it so that it will be exposed to ambient light.

This will still let you set the brightness for dark environments using the trimpot, but it will automatically increase the brightness when the ambient light level is higher.

The three tactile switches are the only components that protrude through the front panel, so you can access them during use. We used switches that are 9mm long (from PCB to tip), which means they are recessed and can only be pressed with a small screwdriver or pen. This avoids them being bumped, and apart from the initial setup, they only need to be accessed when daylight savings starts and ends.

Alternatively, you could use switches that are 15mm tall and they will protrude around 2mm above the case. 12mm tall switches will work too, leaving the switches only slightly recessed.

Solder the switches to the PCB, ensuring that their bottoms are flat against the PCB, so they point straight up.

The final part to attach is the OLED module, MOD1. This needs to be done last.

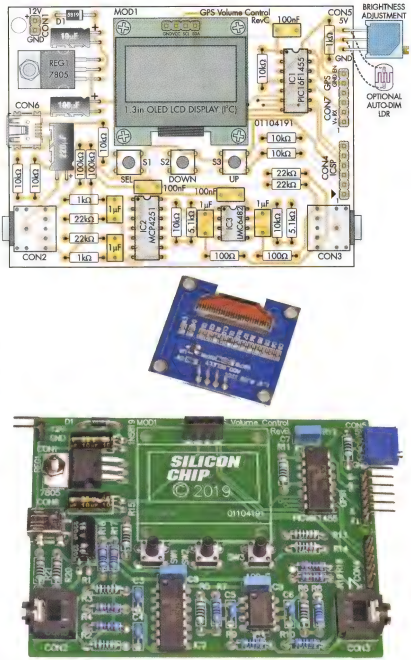
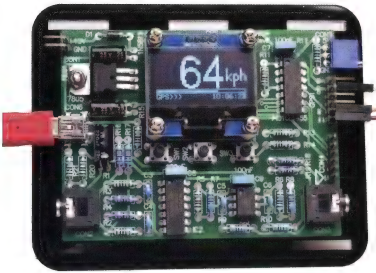


Fig.3: use this PCB overlay diagram and photo as a guide when building the GPS Volume Control. All the taller components, except switches S1-S3, need to be mounted on their side to clear the front panel. Rather than fitting connectors for CON1 and CON7, you can solder wires directly to the PCB. Note the added multi-turn trimpot and LDR for brightness control; you could leave the LDR off or use an LDR and a fixed resistor.



The completed unit inside its purpose-designed, laser-cut acrylic case, obviously without the front case section. CON6 (at left) is a 5V (USB) power input socket; it can also be powered from the 12V DC car supply via CON1. The CON7 header pins at right connect to the GPS receiver.

First, check that the pinout on the module matches that printed on the PCB. If it does not, you will have to remove the four-pin header from the module and use short lengths of hookup wire instead. You may wish to do this anyway, as it will provide some flexibility in assembling the case.

Otherwise, you can just solder a four-way female header to the PCB and plug the module directly into this header. A regular 9mm-high header socket is probably too high, but Altronics offer a low profile (5mm) female header, Cat P5398.

If you are using a 12V supply, now is the time to fit the accessory plug and lead. Fit the twin-core wire into the plug and solder the other end of the wires to the pads on the top left of the PCB, threading it through the adjacent hole for strain relief and checking that the polarity is correct.

With the display module connected, the GPS Volume Control is complete enough to test. If you used a blank PIC, now is the time to program it, using the .hex file found on the SILICON CHIP website.

Testing

At this point, we can check the basic functions of the GPS Volume Control. Start by powering the unit up, either from the 12V input (if REG1 and D1 have been fitted), or from 5V via USB socket CON6.

The display should spring to life, probably showing mostly blank space with "km/h" on the right. Below this will be the volume bar graph set at its midpoint and, below that, the GPS status and a series of dashes. If there is nothing on the display, turn the unit off, as there may be a problem with its construction.

Some GPS modules can take up to 15 minutes to obtain a fix from a cold start, so this display may remain for a while until the GPS unit gets a fix. This can be improved by taking it outside to get a clearer view of the sky.

Even if a fix has not been obtained, you should see two ")" symbols next to the GPS after a few seconds. If you only see one, then the most likely cause is that the GPS module is producing data at the wrong baud rate, or it has been wired incorrectly.

Once a fix has been obtained, the speed will be shown, three ")" symbols will be displayed and the time will be shown instead of dashes. The time may not be correct until the time zone is set.

You can also attach an audio source and test that audio is being passed through undistorted. Even without a GPS fix, an audio signal should make its way through with approximately unity gain.

If everything works as noted, the unit is functional, and you can complete its housing.

Case assembly

We have designed the case so that the matte side of the black front and back panels face outwards, avoiding reflections from the glossy side. Start assembling the case with the back panel.

Feed four of the 10mm M3 machine screws through the rear of the back panel, and secure with M3 Nylon nuts on the other side of the panel. These nuts also act as spacers to keep the PCB clear of the back panel.

If MOD1 has been attached to the PCB via a header socket, unplug it at this stage. If it has been attached with wires, fold it out of the way.

Insert the top and bottom panels of the case into the slots on the rear panel, then thread the PCB over the screw threads and secure it in place by threading the four 9mm tapped spacers on top.

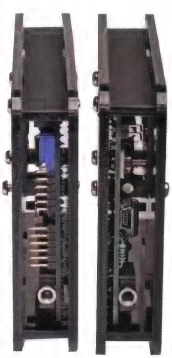
Now sandwich the OLED between the top of the spacers and the back of the front panel. These are then secured by another four 10mm M3 machine screws. We recommend that you use black machine screws for the top to match the top panel colour.

Available functions

On power-up, the main speed screen is shown, with your current speed readout in large digits, with a choice of km/h, mph or knots. Below the speed is a bar graph indicating the current volume, which defaults to mid-level at startup.

Below the volume indication, the GPS status is shown as the letters "GPS" followed by up to three ")" symbols. One means that serial data is being received by IC1, two symbols means that a correctly formed GPS sentence has been detected, and three indicates that satellite lock has occurred and that the GPS data is valid.

At bottom right, the time is shown in hh:mm:ss format. If the GPS does not have a lock, the speed and time displays will be blank, and the volume will not be adjusted.



Left and right edge-on views of the unit in its assembled case. Only four case panels are used so that the connectors on either side of the PCB can be accessed.

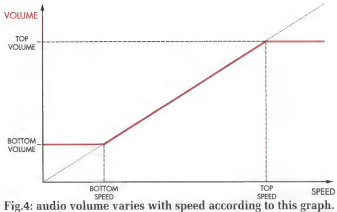


Fig.4: audio volume varies with speed according to this graph. Below the adjustable Bottom Speed, the Bottom Volume is applied. As the speed increases above this, the volume increases linearly until Top Volume is achieved at Top Speed. At higher speeds, the Top Volume is maintained. The volume slowly changes towards its target so that there are no sudden changes in volume with sudden changes in speed.

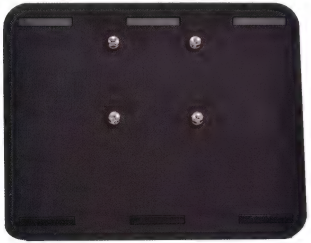
Pressing the left-hand SEL button (S1) cycles through the available settings and then back to the main screen. The settings are: Top Speed, Top Volume, Bottom Speed, Bottom Volume, Units, Time Zone and an option to save the settings to flash memory.

Pressing the DOWN and UP buttons (S2 and S3) will change the currently selected setting. For the speed and volume settings, the values can be set between zero and 255. The speed units can be km/h, mph or kts for km/h, mph or knots respectively.

The time zone offset is set in multiples of 15 minutes from UTC. This is stored as an eight bit signed number, so it can vary between -32:00 and +31:45, although -12:00 to +14:00 is enough to cover the world's current time zones.

The settings take effect immediately although saving to flash (so that the settings are loaded when the device restarts) is done manually, by pressing the UP button when the save option is selected. This avoids excessive wear and tear on the flash memory.

The volume control works as follows. When the speed is at or above Top Speed, the volume is set to Top Volume. When the speed is at or below Bottom Speed, the volume is set to Bottom Volume. In between Top Speed and Bottom Speed, the volume is interpolated linearly. This is shown in graphical format by Fig.4.



On the underside, just four screws are used which hold the PCB, OLED display and other case pieces in place. As mentioned in the parts list, it might look better if the case screws were black (but we didn't have any on hand!).

The Top Speed and Bottom Speed are always referred to in terms of the currently set units. If you plan on driving at more than 255km/h for extended periods, we suggest that you switch the units to knots!

The speed display will read up to 999km/h, which should be sufficient for most users. . .

Setting it up

Before proceeding with the setup, you will need to wire

Parts list – GPS-Based Speedo, Clock & Volume Control

1 double-sided PCB coded 01104191, 92mm x 69mm
1 GPS module with TTL NMEA output (eg, VK2828U7G5LF or SKM53) [Silicon Chip Online Shop Cat SC3362]
1 1.3in SH1106 or SSD1306-based OLED display module (MOD1)
3 tactile pushbuttons with 9mm-15mm shafts (S1-S3)
2 stereo 3.5mm jack sockets (CON2, CON3) [Altronics P0094]
1 6-way right-angle male header (CON4, for programming IC1 in-circuit; optional)
1 mini-USB socket (CON6; optional)
1 6-way right-angle male header (CON7)
1 set of laser-cut acrylic case panels [Silicon Chip Online Shop Cat SC4987]
9 M3 x 10mm machine screws (preferably black; one for REG1, eight for case assembly)
1 M3 nut (for REG1)
4 M3 x 9mm tapped Nylon spacers
4 M3 Nylon nuts
1 length of twin core cable to suit installation (optional, for 12V supply)
1 fused vehicle accessory plug (1A fuse; optional, for 12V supply) [Jaycar PP2001, Altronics P0658]
1 10kΩ LDR (optional; see text)

Semiconductors

1 PIC16F1455 microcontroller, programmed with 0110419A.HEX (IC1)
1 MCP4251-502 dual 5kΩ digital potentiometer (IC2)
1 LMC6482 dual rail-to-rail op-amp (IC3) [Jaycar ZL3482]
1 7805 5V 1A linear regulator (REG1)
1 1N5819 schottky diode (D1)

Capacitors

1 220µF 10V electrolytic
1 100µF 16V electrolytic
1 10µF 16V electrolytic
4 1µF multi-layer ceramic
3 100nF MKT (code 100n, 0.1 or 104)

Resistors (all 1/4W metal film 1%)

2 100kΩ (brown black yellow brown or brown black black orange brown)
4 22kΩ (red red orange brown or red red black red brown)
8 10kΩ (brown black orange brown or brown black black red brown)
2 5.1kΩ (green brown red brown or green brown black brown brown)
3 1kΩ (brown black red brown or brown black black brown brown)
2 100Ω (brown black brown brown or brown black black black brown)
1 10kΩ multi-turn vertical trimpot

TIME ZONE	REGION	OFFSET	DST OFFSET
Australian Western Time	Western Australia	+8:00	No DST
Australian Central Western Time	Eucla	+8:45	No DST
Australian Central Time	South Australia/NT	+9:30	+10:30
Australian Eastern Time	Tas/Vic/NSW/Qld	+10:00	+11:00
Lord Howe Time	Lord Howe Island	+10:30	+11:00
New Zealand Time	New Zealand	+12:00	+13:00
Chatham Island Time	Chatham Islands	+12:45	+13:45

Time zone offsets for the Australia and New Zealand area.

the GPS Volume Control into your vehicle audio system, as described above. You can then power up the unit and press the leftmost button (S1, "SEL") to go to the settings page. By default, all volume settings are 128, so the audio volume will not change.

All volume values are between 0 (off) and 255 (approximately double the incoming volume).

Continue to press SEL until you get to the Units setting, then use the DOWN or UP buttons to select your desired speed unit: kph, mph or kts. Use a similar procedure to set your time zone; see Table 1 above for the appropriate time zone offsets for Australia and New Zealand areas.

All setting take effect immediately and you can scroll down to "Save to FLASH" and press the UP button to store these settings, so they are loaded the next time the GPS Volume Control starts up.

We suggest setting the Top Speed value to between 80km/h and 110km/h, and the Bottom Speed to around 30km/h. In a typical passenger vehicle, there isn't much change in ambient noise from zero to 30km/h.

We also recommend leaving the Bottom Volume value around 128. This means that the GPS Volume Control does not make any volume adjustments at low speeds. You can then adjust the volume of your source or amplifier so that the overall volume through the speakers is satisfactory when stopped.

Now you can adjust the Top Volume, and we recommend having a second person in the car to adjust this while moving, so the driver is not distracted.

You could start with a value of say 192, giving a roughly 50% increase perceived volume at the Top Speed. As you are driving, once you have reached or exceeded your Top Speed setting, wait a little time for the unit to ramp up to its maximum volume setting. It takes the unit around 11 seconds to go from zero to 255, so it should not take much more than five seconds to reach maximum volume.

On the main screen, you can check the bar graph to confirm that the volume has settled where expected.

Take note of whether the audio while moving at this speed level is too loud, too quiet or just right. If it was too loud or too quiet, you can pull over later and make an adjustment (or get your passenger to do it for you).

Repeat until you are satisfied, then save the settings to flash.

Note that you may need to adjust the Bottom Volume value below 128 to give more range if you find you have set the Top Volume value to 255 and you would prefer it to be higher. SC

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Digital Signal Processor . . . Two-way Active Crossover . . . Eight-channel Parametric Equaliser . . .

IT'S ALL OF THESE...

and more!

We introduced our new, very versatile hifi stereo digital signal processor (DSP) last month. As we said then, it is a monster project, built with seven modules. Based around a powerful 32-bit PIC processor and high-quality analog-to-digital (ADC) and digital-to-analog (DAC) converters, it can be used as a two-way active crossover and/or a multi-band parametric equaliser – and much more! In this second instalment, we finish describing the circuit and present the parts list and board assembly instructions.

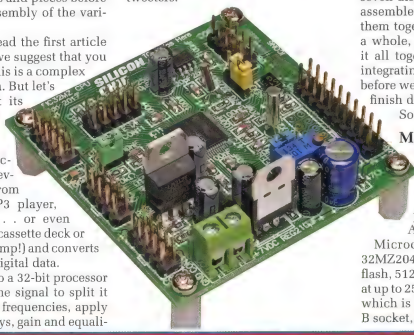
We rather left you hanging at the end of the article last month, because we didn't have room to describe all the circuitry in this advanced device. We'll rectify that shortly, covering the CPU board and some extra bits and pieces before we get into the assembly of the various modules.

If you haven't read the first article in the May issue, we suggest that you do so now, since this is a complex and capable design. But let's just briefly revisit its capabilities before continuing the circuit description.

This device accepts a stereo line-level audio signal (from a disc player, MP3 player, smartphone etc . . . or even *[cough splutter!]* a cassette deck or turntable with preamp!) and converts it to high-quality digital data.

It then sends it to a 32-bit processor which processes the signal to split it into high and low frequencies, apply any necessary delays, gain and equalisation before feeding the results to two hifi stereo DAC boards.

These convert the digital signals back into two pairs of stereo signals which can then be fed onto individual power amplifiers for the woofers and tweeters.



It's controlled using a graphical LCD, rotary encoder and two pushbuttons and the configuration is stored in an EEPROM chip, so you don't have to set it up each time.

For flexibility, It's built using seven distinct modules. Once you've assembled these, you can connect them together and test the system as a whole, then start work on putting it all together in a proper case and integrating it with a hifi system. But before we get to that stage, we need to finish describing how it works.

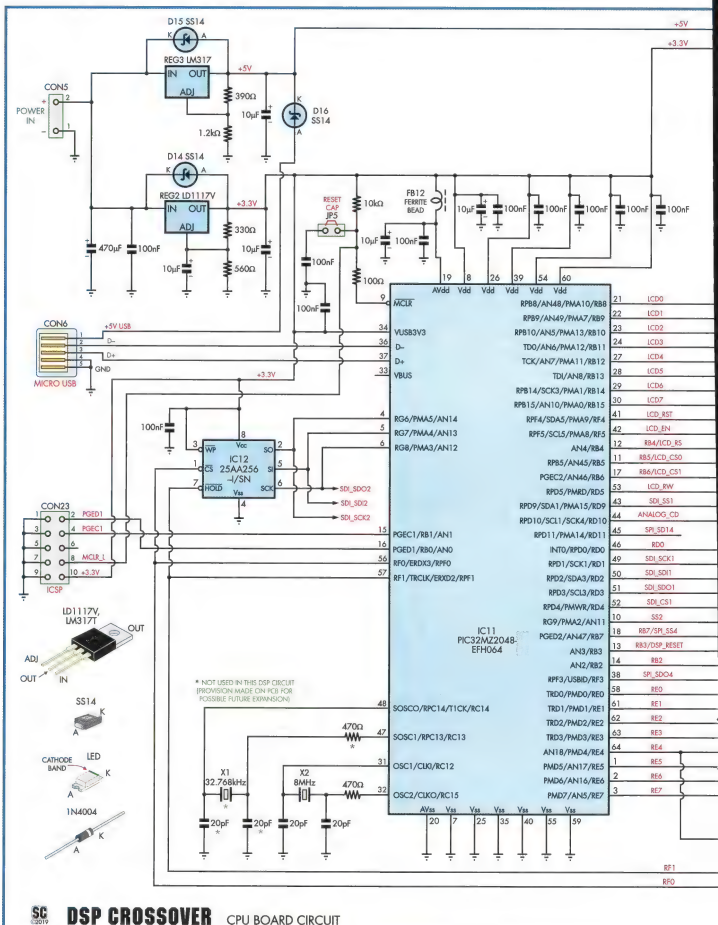
So let's get back to it.

Microcontroller board

The circuit of the microcontroller board is shown in Fig.7. This is designed so that it can be used in other projects (just as you can the ADC and DAC boards).

Microcontroller IC11 is a PIC32MZ2048 32-bit processor with 2MB flash, 512KB RAM and which can run at up to 252MHz. It has a USB interface which is brought out to a micro type-B socket, CON6, although we haven't

Part II – Design by Phil Prosser . . . Words by Nicholas Vinen



DSP CROSSOVER CPU BOARD CIRCUIT

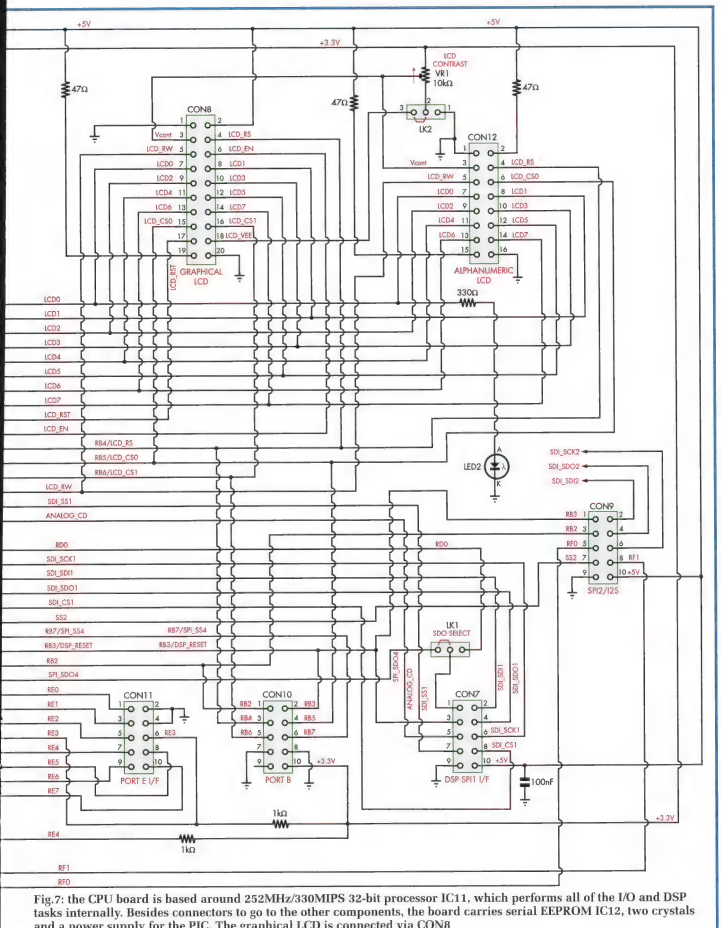
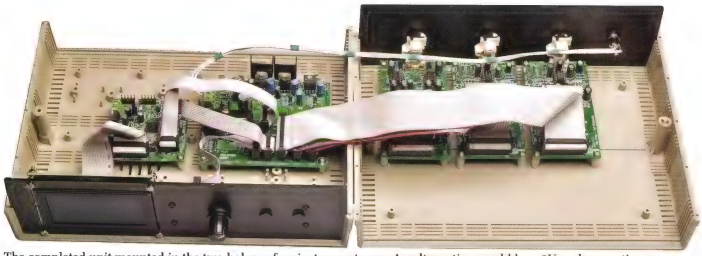


Fig.7: the CPU board is based around 252MHz/330MIPS 32-bit processor IC11, which performs all of the I/O and DSP tasks internally. Besides connectors to go to the other components, the board carries serial EEPROM IC12, two crystals and a power supply for the PIC. The graphical LCD is connected via CON8



The completed unit mounted in the two halves of an instrument case. An alternative would be a 2U rack-mounting case.

used it in this project – it's there 'just in case' for other projects.

The PIC is also fitted with an 8MHz crystal for its main clock signal (X2). Provision is made on the PCB (and shown in the circuit) for a 32.768kHz crystal for possible future expansion but they are not used in this project and can be left out.

There is also provision for an on-board serial flash (IC12) which is connected via one of the hardware SPI ports.

Two of the other audio-capable SPI ports are wired up to CON7, which connects to CON17 on the power supply/signal routing board (described last month), and therefore ultimately to the ADC and DAC boards.

LK1 allows two different pins to be used for SDO4 (serial data output #4); this function can be internally reconfigured in IC11, and since some functions are shared, there may be times where you want to use the alternative pin.

CON11 on this board connects to CON18 on the power supply/routing board and feeds the master clock (MCLK) through to the ADC and DACs, from output pin RE5 of IC11. As mentioned earlier, the other I/O pins connect to the front panel control board. Its circuit is shown in Fig.8. It carries two pushbutton switches and a rotary encoder, which are used to scroll through menus and make selections.

The user interface is displayed on a graphical LCD, which is wired up to CON8 on the micro board, via a ribbon cable. This provides a reasonably standard 8-bit parallel LCD drive interface. The eight LCD data lines (DB0-DB7) are driven from a contiguous set of digital outputs of IC11 (RB8-RB15). This allows a byte of data to be transferred to the display with just a few lines of code and minimal delay.

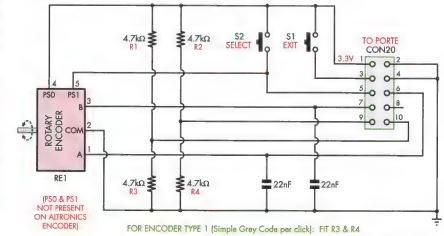
The other LCD control lines are driven by digital outputs RB4, RB5, RB6, RD5, RF4 and RF5 and the screen is powered from the 5V rail, with the backlight brightness set with a 47Ω resistor. LCD contrast is adjusted using trimpot VR1, which connects to CON8 via LK2.

LK2 is provided so that VR1 can also be used to set the contrast on an alphanumeric LCD, which can be fitted in place of the graphical one and controlled by same pins (via CON12). But again, we are not using that in this project. As we said above, this board is intended to be generic, so it has a few options we are not using.

CON23 is a somewhat unusual in-circuit serial programming (ICSP) header. It has a similar pinout to a PICkit 3/4 but not directly compatible; it's designed to work over a longer cable. Since each signal line has at least one ground wire between it, signal integrity should be better.

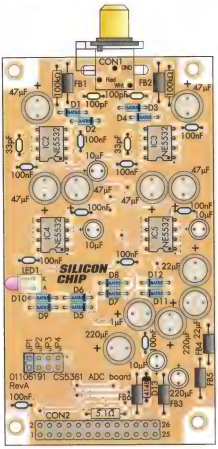
Jumper leads could be used to make a quick connection to a PICkit to program the microcontroller the first time. Or you could attach a 10-pin IDC connector to the end of a ribbon cable and then solder the appropriate wires at the other end of the cable to a 5-way SIL header as a more permanent programming adaptor for development use.

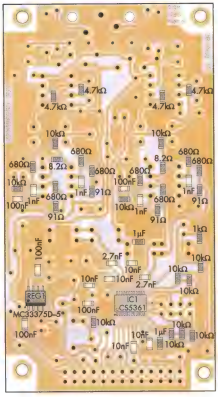
There are two regulators on the board; REG3 derives a 5V supply from 7V+ DC applied to CON5, which is used to power the LCD screen and is

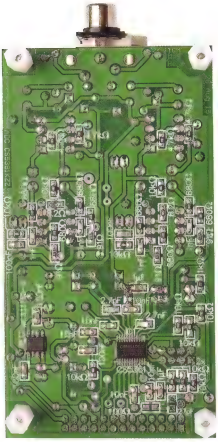


SC 120079 **DSP ACTIVE CROSSOVER** FRONT PANEL CIRCUIT

Fig.8: the front panel circuit is elementary. Two momentary pushbuttons and a quadrature (incremental) rotary encoder to CON20, which is wired back to the signal routing board and then onto the PIC32. Different combinations of resistors R1-R4 are fitted so that the CPU knows what sort of signals to expect from the rotary encoder. The two capacitors help to debounce the encoder's digital outputs.







... and here's the underside photo to assist you with construction (the top side was shown last month). The use of IC sockets is optional but highly recommended – just in case, just in case!

Fig.9: the ADC board has components on both sides; SMDs on the bottom and through-hole components on the top. Be careful with the polarity of the ICs, REG1, D1-D13 and the electrolytic capacitors. Note that diodes D1-D12 do not all face in the same direction...

also fed to CON7 and CON9. REG2 is used to produce a +3.3V rail from the same source (CON5), to power microcontroller IC11 itself.

However, note that in this project, we're not feeding power in via CON5. Instead, the 5V supply comes from the main power supply board over the ribbon cable to CON7. It then powers the LCD screen and flows through schottky diode D15 to the input of REG2, which then powers REG2 and thus the 3.3V rail for the micro.

We're also not using the USB interface or USB connector CON6 in this project, nor are we using the extra microcontroller I/O pins which are broken out to headers CON9 or CON10. CON9 could potentially be used to connect another ADC and/or DAC board in other applications where more channels may be necessary (eg, a three-way crossover).

LED2 is connected from LCD data line LCD0 to ground, with a 330Ω current limiting resistor, so it will flash when the LCD screen is being updated.

Front panel board

The front panel circuit, Fig.8, was mentioned above. In addition to the two pushbuttons and rotary encoder, there are four 4.7kΩ resistors shown, but only two of these are actually fitted.

These resistors indicate to the CPU board what type of rotary encoder has been fitted and therefore how to interpret the data from it.

R3 and R4 are fitted when a standard gray code or 'quadrature' rotary encoder, which is a standard encoding method but not used by either of the encoders we tested.

R1 and R4 are fitted when an encoder is used which produces the same quadrature signals but it goes through one complete (four-pulse) cycle for each step that the encoder is rotated (ie, 11 -> 10 -> 00 -> 01 -> 11 clockwise or 11 -> 01 -> 00 -> 10 -> 11 anti-clockwise). This is the code that the Altronics S3350 rotary encoder produces.

R2 and R3 are fitted for an encoder which produces three state changes per click (11 -> 10 -> 00 -> 11 clockwise or 11 -> 01 -> 00 -> 11 anti-clockwise). This is the code that the Jaycar SR1230 rotary encoder produces. If this encoder is used, pushbutton S1 does not need to be fitted as the encoder has an internal pushbutton, activated by pressing in the knob, which is connected in parallel with S1.

The two 22nF capacitors help to debounce the signals from the rotary encoder, to ensure that it works reliably.

Debouncing is also performed in software, but it helps to have the hardware to reduce glitches at the digital inputs.

The PCB has two different mounting locations for the two possible rotary encoders, because the Jaycar SR1230 is a vertical type while Altronics S3350 is right-angle mounting.

Therefore, if using the Altronics encoder, you would either need to chassis-mount the pushbuttons and wire them back to the board, or surface-mount the encoder on the board so that it is vertical (more on that later).

Construction

Start by assembling the PCBs. We'll do that in the same order that we presented the circuit, starting with the ADC board. This is built on a PCB coded 01106191, measuring 55.5 x 102mm. The overlay diagrams for this board

are shown in Fig.9.

It has parts on both sides - SMDs on the bottom and through-hole on the top, so both sides are shown in Fig.9.

It's best to fit all the SMD parts to the underside first, starting with IC1. This is the only fine-pitch part on the board. It comes in a 24-pin TSSOP package. First, identify the pin 1 dot printed on its top surface and orientate the part so that dot is towards the nearby DIL header as shown. Then put a little solder on one of the corner pads and heat that solder while sliding the chip into position.

Use a magnifier to check that all the pins on both sides are correctly lined up with their pads. If not, re-heat the solder on that one pin and gently nudge the IC ever so slightly in the right direction. Repeat until it is properly lined up, then tack down the pin in the opposite corner.

Next, spread a thin smear of flux paste over all the pins, then load your soldering iron tip with a little solder and run it along the pins on one side. Stop and add more solder if you are running out and repeat until there is enough solder on all pins. Don't worry if some are bridged; we'll clean that up later. Repeat for the other side.

Now add more flux paste to any areas where you suspect there may be bridges and apply some solder wick. Wait for the flux to smoke and the solder to reflow into the wick before sliding it away from the IC. Repeat for any suspected bridges, then clean that area of the board using flux residue remover, isopropyl alcohol or methylated spirits and inspect it under magnification.

Again using a magnifier, make sure there is solder from each pin to the pad below and that none are bridged. Add a little flux and then a dab of solder to any pins which do not appear to be soldered properly. Use the procedure described above to remove any bridges. Clean and re-inspect until you are happy that all the solder joints are good.

Now move on to REG1, which has much bigger and more widely spaced pins. Use a similar procedure to solder it in place, again ensuring that its pin 1 dot is orientated correctly, ie, on the side facing the DIL header.

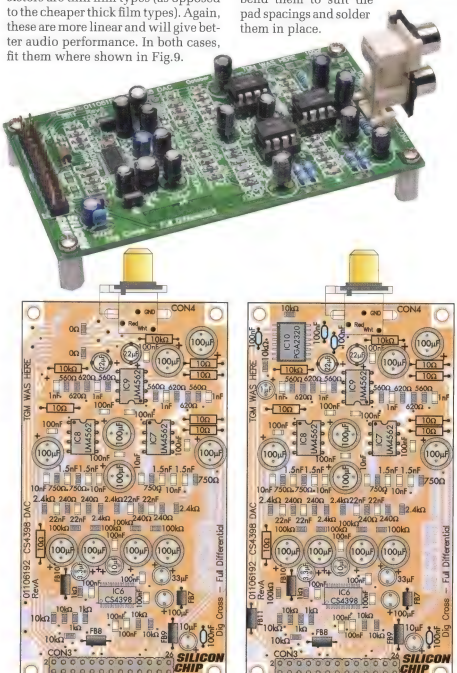
Now move onto the SMD resistors and capacitors. You can use a similar procedure – load one pad with a little solder, slide the part in place while heating that solder, check its orientation, then wait for the first joint to solidify and solder the opposite side of the part to its pad. Add a dab of flux paste to the first pad and touch it with your soldering iron to reflow that joint and ensure it is nice and smooth.

Note that some capacitors are specified as C0G/NP0 types. These are important to obtain good audio quality as they are far more linear than X5R, X7R or Y5V dielectrics. Similarly, some resistors are thin film types (as opposed to the cheaper thick film types). Again, these are more linear and will give better audio performance. In both cases, fit them where shown in Fig.9.

Through-hole components

Now flip the board over and start fitting the axial through-hole components, starting with the three resistors, then the 13 diodes. Be careful that the diode cathode stripes face as shown in Fig.9, noting that many of them face in different directions, and make sure D13 is the larger type.

Follow with the ferrite beads; if yours are just loose beads, feed diode lead off-cuts through them and then bend them to suit the pad spacings and solder them in place.



Figs.10a (left) and 10b (right): unlike the ADC board, this DAC board has a mixture of through-hole and SMD components on the top side, and no components on the bottom side. The version at the left is what's required for this project; the version at right has optional volume control IC10 fitted.

Next, solder the IC sockets in place and make sure they are orientated as shown. You could solder the ICs directly to the board, which would give better long-term reliability, but that would make it harder to swap the chips over in future if you needed to do that.

Now fit the ceramic capacitors. The 100nF multi-layer types are shown in blue in Fig.9 while the others are shown in yellow. Follow with the electrolytic capacitors, ensuring that in each case, the longer lead goes through the pad marked with a "+" symbol. You may need to bend the leads in some cases to match the hole spacings on the PCB.

Next mount the headers for CON2 and JP1-JP4. You can snap these from a longer dual-row pin header strip. Make sure they have been pushed down fully before soldering the pins.

We soldered the clipping LED (LED1) directly to the board but you could fit a 2-pin header instead, and run leads to a front panel clip indicator LED. Either way, the longer anode lead should be connected to the pad marked "A" on the PCB.

The last part soldered to the board is CON1, the dual vertical RCA socket. We found that we had to use a 2.5mm drill bit, turned by hand, to slightly elongate the holes for the plastic posts before it would fit into the board. This has the advantage (compared to specifying larger holes on the PCB), of ensuring a very tight fit which provides good mechanical anchoring for the sockets.

Once you've pushed the sockets into their mounting holes (be careful not to break the plastic!), solder the three pins. You can then plug op amps IC2-IC5 into their sockets, and shorting blocks JP1-JP4 into position, and this board is complete.

Moving on to the DAC board

Two identical stereo DAC boards are required to provide the four audio outputs in this project. You can assemble them one at a time or in parallel. The overlay diagram for this PCB is shown in Fig.10(a).

It's another double-sided board, coded 01106192 and measuring 55 x 101mm.

This time, there are no components on the bottom side, but there is a mixture of SMD and through-hole components on the top. The version on the right, Fig.10(b), shows IC10 and its associated components fitted. But those are not required for this project, so build the version at left.

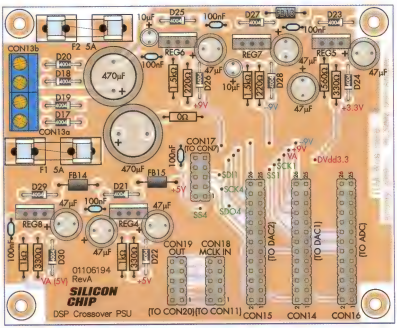
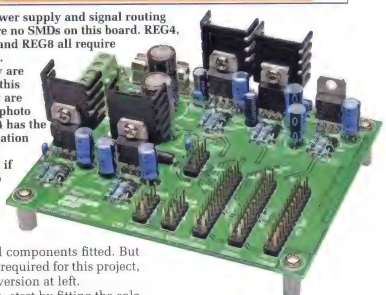


Fig.11: the power supply and signal routing PCB. There are no SMDs on this board. REG4, REG6, REG7 and REG8 all require flag heatsinks. Although they are not shown in this diagram, they are shown in the photo at right. REG4 has the highest dissipation so fit a larger heatsink to it, if possible. Also note the various test points.



Once again, start by fitting the sole fine-pitch IC to the board. IC6 is in a 28-pin TSSOP package. Use the same procedure as described above, for IC1 on the ADC board.

Then solder all the SMD resistors and capacitors, again using the same procedure as before.

Note that all the SMD capacitors with values below 100nF should be C0G types and many of the resistors are thin film types, again for linearity, to provide low distortion.

The two 0Ω resistors are soldered across pads 9 & 11 and 14 & 16 of IC10's footprint, so that the audio bypasses this chip and goes straight to the output.

Be careful to avoid shorting these pins to pins 10 and 15 in between, as those connect to ground, so you won't get any output on that channel if there is a solder bridge.

You can now fit the through-hole axial components, ie, the remaining resistors and the ferrite beads, followed by the IC sockets for IC7-IC9. Be careful with the orientation of these sockets as they don't all face in the same direction.

Next, mount the single through-hole ceramic capacitor, followed by the electrolytics, again taking care to ensure that the longer leads go to the pads marked "+". Then fit DIL header CON3, followed by dual RCA socket CON4. Again, you will probably have to slightly enlarge the bigger PCB mounting holes to get the socket to fit into the board.

Plug the op amps into the sockets, making sure each pin 1 dot lines up with the notch in the socket (check

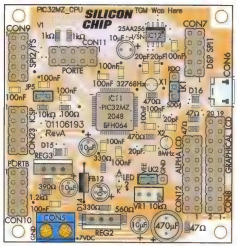


Fig.12: the CPU board uses mostly SMD parts, but there are also some through-hole parts and connectors, all on the top side. Note the orientation of IC12, IC13 and MELF diodes D14-D16. The jumpers for LK1, LK2 and JP5 are shown in their normal operating positions for this project.

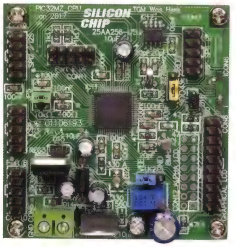


Fig.10 if you're unsure) and the DAC boards are finished.

You can then move onto the power supply and signal routing board.

Power supply board assembly

There are no SMDs on this board. It's built on a double-sided PCB coded 01106194 which measures 103.5 x 84mm.

Overlay diagram Fig.11 shows where the components go.

Start by fitting the resistors as shown, then the diodes, which are all 1N4004 types. But they face in different directions, so check carefully to make sure the cathode stripes are orientated as shown in Fig.11.

You can then mount the ferrite beads, as before, using component lead off-cuts if they do not have their own leads. You can also use a component lead off-cut instead of the 0Ω resistor.

Then fit the pin headers, ensuring that each one is pushed down fully before soldering. As mentioned earlier, these can be snapped from longer dual-row headers, as long as they are snappable types. Follow with the ceramic capacitors, then the electrolytic capacitors. In each case, the longer lead goes into the pad marked with a "+" sign.

Now solder the four fuse clips in place, with the fuses clipped into each pair to ensure that the retaining tabs are on the outside and that they line up properly.

Ideally, use a blown fuse while soldering and then replace it with the specified fuse once the clips have cooled down. You will a need quite hot iron to get the solder to flow well, and use a generous amount.

Next, dovetail the two 2-way terminal blocks together (if you don't have a 4-way block) and solder it with the wire entry holes facing the edge of the board.

Before fitting the regulators, consider how you are going to mount the heatsinks. We used 6021-type flag heatsinks but mounted them upside-down to avoid fouling components around the regulators, because we had pushed the TO-220 packages all the way down before soldering them.

We think that this will also reduce temperatures on the board, because it keeps the fins away from the board, and allows cooling air to more easily circulate.

But if you want to fit flag heatsinks 'right-way-up', you could do so by fitting them to the regulators first before pushing them down, then lifting them slightly before soldering the leads.

Note that REG4, which supplies 5V to the CPU board and for the LCD, has quite high dissipation.

If you can fit a bigger heatsink than specified to this regulator, that would be even better. But the 6021-type should be adequate. REG5 does not need a heatsink as its dissipation is quite low.

Having sorted out the heatsinking, fit the five regulators. REG7 is the LM337 negative type; the other four are all LM317s, so don't get them mixed up.

Once the regulators and heatsinks are installed, the power supply board is finished and you can move onto the last major board, which hosts the main CPU.

CPU board assembly

This board is smaller and has mostly SMD components. It's built on a double-sided PCB coded 01106193 which measures 60.5 x 62.5mm. Fig.12 shows where the components go.

Start with the CPU, IC11, which is in a 64-pin quad flat pack. Its pin pitch is slightly larger than the TSSOPs but it has pins on all four sides. Use the same basic technique, but make sure that the pins on all four sides are properly lined up on their pads before soldering more than one pin. Follow with IC12, an 8-pin SOIC package device, which is a much simpler affair.

Then move onto the SMD capacitors and resistors, followed by LED2. SMD LEDs typically have a green dot or marking to indicate the cathode, and this is on the opposite side from the anode, which goes to the pad marked "A" on the PCB. But it's best to check the LED with a DMM set to diode test mode before soldering it. If it lights up, the red probe is on the anode.

Next, fit SMD diodes D14-D16. These are schottky diodes in a MELF cylindrical package. We used "SMA" (DO-214AC) package diodes on our prototype, but they barely fit on the provided pads and are much trickier to solder. The MELF diodes will be much easier. Like through-hole diodes, they have a stripe at the cathode end and this must be orientated as shown in Fig.12.

Now you can solder ferrite bead FB12 in place, followed by pin headers CON7-CON11 and CON23. There is no need to fit a header for CON12. You can also now fit the pin headers for LK1, LK2 and JP5, followed by optional screw terminal block CON5, with its wire entry holes towards the nearest edge of the board.

Next, mount crystals X1 and X2, taking care to avoid putting too much stress on the leads as they are relatively thin. Gently bend them to fit the pad spacings.

If using a large (HC-49 style) crystal for X2, fit an insulating washer underneath it so that its metal can won't short on any of the components below, since the leads may not be stiff enough to hold it firmly in place without resting on them.

You can then install trimpot VR1, with its adjustment screw positioned

as shown, followed by the electrolytic capacitors, with their longer leads to the pads marked "+".

Solder REG2 & REG3 in place, with the metal tabs orientated as shown. Don't get them mixed up as they are different types - REG3 is a standard LM317 adjustable regulator while REG2 is a special low-dropout type. Neither requires a heatsink.

Finally, insert the jumper shunts for LK1, LK2 and JP5 as shown in Fig.12.

Front panel & LCD assembly

This board has just a few components and is fitted just behind the unit's front panel, next to the LCD, allowing the rotary encoder shaft and pushbuttons to poke through holes drilled in that panel. It's built on a double-sided PCB measuring 107.5 x 32.5mm. The PCB overlay diagram is shown in Fig.13.

Start by fitting the resistors. Four are shown in Fig.13, but only two are fitted, as shown on the circuit diagram, Fig.8. For the Altronics S3350 rotary encoder, fit R1 and R4. For the Jaycar SP0721 encoder, fit R2 and R3.

Follow with the two 22nF capacitors, which should either be fitted to the underside of the board, as shown in Fig.13, or laid over on the top side of the board, so they will clear the front panel. Then solder the 10-pin DIL header in place, on the underside of the board.

That just leaves the rotary encoder and pushbutton(s). As explained earlier, if you're using the Jaycar rotary encoder (or an equivalent), it has an integral pushbutton, so you don't need to fit S2. You can still fit S2 if you want; it will merely provide an alternative way to use the SELECT function.

Also keep in mind that if you use the Jaycar encoder, this board is then mounted directly to the front panel of the unit.

But if you fit the Altronics encoder in the usual manner, ie, with its shaft parallel to the PCB, you would need to mount it differently, and that would probably require S1 and S2 to be mounted directly on the front panel and wired back to this board (two wires required for each).

To avoid that, you could bend RE2's three pins down and mount it vertically on the board, like RE1. You would need to solder stiff wire to its two mounting lugs, bend these over under the board and attach them to the mounting holes using a generous amount of solder, to provide sufficient mechanical strength.

Once RE1/RE2 and S1/S2 are in place, this board is finished.

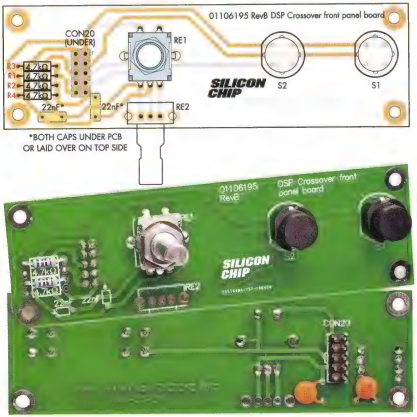


Fig.13: the front panel PCB. Note that only one of RE1 (Jaycar SR1230) or RE2 (Altronics S3350) is fitted and in the case where RE1 is used, pushbutton S2 is redundant and may be left off. Also, if RE1 is fitted, fit resistors R2 and R3; if RE2 is fitted, fit resistors R1 and R4.

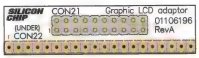


Fig.14: the LCD adaptor is dead simple and just connects pins 1-16 of DIL header CON21, mounted on the top side, to pins 1-16 of SIL header CON22, on the other side of the board. You could use a header socket for CON22, but it will be more reliable if you solder it to the LCD pin header.

Building the LCD adaptor

The LCD has a 20-pin SIL header, but it is connected to the CPU board via a 10x2 pin DIL header and DIL IDC connectors.

So we have designed a small adaptor board to make this a 'plug and play' affair. It's coded 01106196, measures 51 x 13mm and shown in Fig.14. The only parts on this board are the SIL and DIL headers.

Most suitable LCD screens have a 20-pin header with pin 1 (Vss/GND) at right (looking at the LCD screen with the connector at the bottom) and pin 20 (K-) at left. If your screen has a different pinout then you will need to come up with a different connecting arrangement.

Start by soldering a 20-pin SIL header to the LCD, on the back of the board (ie, the opposite side to the LCD screen), with the longer pins projecting out the back. Then solder the DIL pin header to the top side of the adaptor board, as shown in Fig.14.

You can then place this adaptor board over the pin header sticking out the back of the LCD, making sure that its pin 1 at left lines up with pin 1 on the LCD. Solder all 20 pins.

Making up the cables

You will need seven interconnecting cables to complete the unit, and they're also handy to have for testing, so let's make them up now. These are shown in Fig.15.

There are three 10-way cables, one 40cm long and two 15cm long; one 20-way cable, 30cm long; and three 26-way cables, 20cm, 30cm and 35cm long. Cut each section of ribbon cable to length, leaving around 5cm extra

PARTS LISTS

Stereo ADC input board

1 double-sided PCB coded 01106191, 55.5 x 102mm
1 dual vertical RCA socket (CON1)
1 13x2 pin header (CON2)
4 8-pin DIL IC sockets (for IC2-IC5)
1 4x2 pin header (JP1-JP4)
4 jumper shunts (JP1-JP4)
6 ferrite beads (FB1-FB6)

Semiconductors

1 CS5361-KZZ or CS5381-KZZ high-performance stereo ADC, TSSOP-24 (IC1)
4 NE5532 dual low-noise op amps, DIP-8 (IC2-IC5)
1 MC33375D-5.0R2G SMD low-dropout linear regulator, SOIC-8 (REG1)
1 5mm red LED (LED1)
12 BAT85 schottky diodes (D1-D12)
1 1N4148 small signal diode (D13)

Through-hole capacitors

3 220µF 10V electrolytic
6 47µF 25V electrolytic
2 22µF 50V electrolytic
4 10µF 50V electrolytic
1 1µF 50V electrolytic
10 100nF 50V multi-layer ceramic
2 100pF C0G/NP0 ceramic
2 33pF C0G/NP0 ceramic

SMD capacitors (all 2012/0805 X7R unless otherwise stated)

2 1µF 6.3V
5 100nF 50V
5 10nF 50V
2 2.7nF 50V C0G/NP0 5%
4 1nF 50V C0G/NP0 5%

Resistors (all SMD 2012/0805 1% unless otherwise stated)

2 100kΩ through-hole 1/4W 1% metal film
11 10kΩ
4 4.7kΩ thin film*
1 1kΩ
8 680Ω or 681Ω thin film*
4 91Ω thin film*
2 8.2Ω
1 5.1Ω through-hole 1/2W 1% or 5%

** eg, Yageo RT0805FRE07 or RT0805FRE13 series*

Stereo DAC output board (per board, two required)

1 double-sided PCB coded 01106192, 55 x 101mm
1 13x2 pin header (CON3)
1 dual vertical RCA socket (CON4)
3 8-pin DIL IC sockets (for IC7-IC9)
4 ferrite beads (FB7-FB10)

Semiconductors

1 CS4398-CZZ high-performance stereo DAC, TSSOP-28 (IC6)
3 LM4562 dual ultra-low-distortion op amps, DIP-8 (IC7-IC9)
1 PGA2320IDW stereo volume control chip, SOIC-16 (IC10; optional - see text)

Through-hole capacitors

11 100µF 16V electrolytic
1 33µF 25V electrolytic
2 22µF 50V electrolytic
2 10µF 50V electrolytic
1 3.3µF 50V electrolytic
1 100nF 50V multi-layer ceramic

SMD capacitors (all 2012/0805 50V ceramic)

12 100nF X7R
4 22nF C0G/NP0 5%
4 10nF C0G/NP0 5%
4 1.5nF C0G/NP0 5%
4 1nF C0G/NP0 5%

Resistors (all SMD 2012/0805 1% unless otherwise stated)

2 10kΩ through-hole 1/4W 1% metal film
5 100kΩ
5 10kΩ
4 2.4kΩ or 2.43kΩ thin film*
3 1kΩ
4 750Ω thin film*
4 620Ω thin film*
4 560Ω thin film*
4 240Ω thin film*
6 10Ω through-hole 1/4W 1% metal film
2 0Ω

** eg, Yageo RT0805FRE07 or RT0805FRE13 series*

Extra parts needed if IC10 is fitted

1 ferrite bead (FB11)
1 1µF 50V electrolytic capacitor
3 100nF 50V multi-layer ceramic through-hole capacitors
1 100kΩ SMD 2012/0805 1% resistor
2 10kΩ SMD 2012/0805 1% resistors

CPU board

1 double-sided PCB coded 01106193, 60.5 x 62.5mm
1 2-way mini terminal block, 5.08mm spacing (CON5; optional)
5 5x2 pin headers (CON7,CON9-CON11,CON23)
1 10x2 pin header (CON8)
2 3-pin headers (LK1,LK2)
1 2-pin header (JP5)
3 shorting blocks (LK1,LK2,JP5)
1 ferrite bead (FB12)
1 32768Hz watch crystal (X1)
1 miniature 8MHz crystal (X2) OR
1 standard 8MHz crystal with insulating washer (X2)
1 10kΩ vertical trimpot (VR1)

Semiconductors

1 PIC32MZ2048EFH064-250I/PT 32-bit microcontroller programmed with 0110619A.HEX, TQFP-64 (IC11)
1 25AA256-I/SN 32KB I^2C EEPROM, SOIC-8 (IC12)
1 LD1117V adjustable 800mA low-dropout regulator, TO-220 (REG2)
1 LM317T adjustable 1A regulator, TO-220 (REG3)
1 blue SMD LED, SMA or SMB (LED2)
3 LL5819 SMD 1A 40V schottky diodes, MELF (MLB) (D14-D16)

Capacitors

1 470µF 10V electrolytic
5 10µF 50V electrolytic
11 100nF SMD 2012/0805 50V X7R
4 20pF SMD 2012/0805 50V C0G/NP0

Resistors (all SMD 2012/0805 1%)

1 10kΩ	1 1.2kΩ	2 1kΩ
2 470Ω	1 560Ω	1 390Ω
2 330Ω	1 100Ω	3 47Ω

Front panel interface

1 double-sided PCB coded 01106195, 107.5 x 32.5mm
1 5x2 pin header (CON20)
2 4.7kΩ 1/4W through-hole resistors
2 22nF through-hole ceramic capacitors
2 PCB-mount snap-action momentary pushbuttons (S1,S2)* [Jaycar SP0721, Altronics S1096]
1 3-pin rotary encoder (RE1/RE2) [eg, Altronics S3350 or Jaycar SR1230 with integrated pushbutton]
1 knob (to suit RE1/RE2)

* only one required if using Jaycar SR1230 encoder

Power supply/routing board

1 double-sided PCB coded 01106194, 103.5 x 84mm
4 M205 fuse clips (F1,F2)
2 5A M205 fast-blow fuses (F1,F2)
3 ferrite beads (FB13-FB15)
2 2-way terminal blocks, 5.08mm pitch (CON13)
3 13x2 pin headers (CON14-CON16)
3 5x2 pin headers (CON17-CON19)
4 6021 type mini-U TO-220 heatsinks (for REG4 & REG6-REG8) [Jaycar HH8504, Altronics H0635]

Semiconductors

4 LM317T adjustable 1A regulators, TO-220 (REG4-REG6,REG8)
1 LM337T adjustable -1A regulator, TO-220 (REG7)
14 1N4004 400V 1A diodes (D17-D30)

Capacitors

2 470µF 16V electrolytic
7 47uF 25V electrolytic
2 10uF 50V electrolytic
6 1000nF 50V through-hole multi-layer ceramic

Resistors (all 1/4W 1% metal film)

2 1.5kΩ 2 1kΩ 1 560Ω
3 330Ω 2 220Ω

LCD assembly

1 128 x 64 pixel graphical LCD with 16-pin connector
1 double-sided PCB, coded 01106196, 51 x 13mm
1 13x2 pin header
1 16-pin header

Chassis parts, connecting cables etc

1 2U rackmount case or similar
1 M205 'extra safe' fuseholder
1 1A slow-blow M205 fuse
1 5A 250VAC DPST or DPDT switch
28 9mm long M3 tapped spacers
56 M3 x 5mm black panhead machine screws
3 No.2 x 6mm self-tapping screws
1 1m length of 26-way ribbon cable#
1 30cm length of 20-way ribbon cable#
1 1m length of 10-way ribbon cable#
6 26-pin IDC line plugs
2 20-pin IDC line plugs
6 10-pin IDC line plugs
1 1m length 10mm diameter heatshrink tubing
10 small cable ties
4 instrument feet with mounting screws
or 1.3m length 26-way(+) ribbon cable

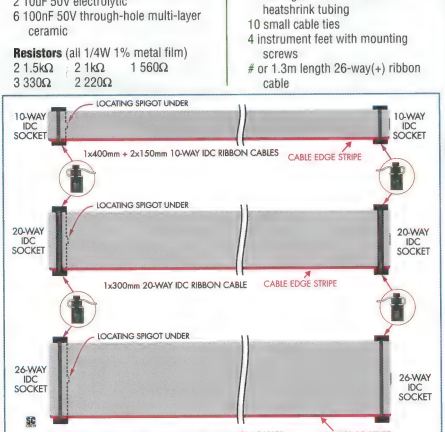


Fig.15: here's how to make up the seven ribbon cables required to connect the various boards together. Three ten-way cables are required in two different lengths, plus one 20-way cable and three 26-way cables, each a different length.

in each case for crimping to the connectors.

You can strip these cables out of ribbon cables with more wires, by making a small cut between two wires and then separating the sections by pulling them apart.

It's best to use a dedicated IDC crimping tool for this job, such as Altronics T1540. You can use a vice, but you have to be careful to avoid crushing and breaking the plastic IDC connectors.

Each connector has three parts: the bottom part, which has the metal blades that cut into the ribbon cable; the middle part, which clamps the cable down onto these; and a locking bar at the top that holds it all together once it has been crimped.

Note how, as shown in Fig.15, the cable passes between the locking bar and upper part before folding over on the outside edge and then being crimped underneath.

So with this in mind, slightly separate the three pieces without actually taking them apart, and feed the ribbon cable through as shown. Ensure there is enough "meat" for the metal blades to cut into, then place it into your crimping tool or vice without allowing the cable to fall out. Clamp the three pieces together, gently at first, then more firmly.

The trick is to crimp it hard enough to ensure that the blades cut fully through the insulation and make good contact with the copper wires, without pressing so hard that you break the plastic.

If using a vice, it's best to wedge a piece of cardboard between each end of the connector and the vice, to provide some cushioning.

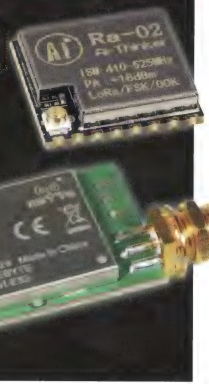
Once you've crimped a connector at one end of the cable, do the one at the other end, making sure that when you're finished, the locating spigots will both be facing in the same direction – see Fig.15. Then repeat this procedure for all the other cables that are required.

Next month

The final article in this series will cover testing all of these assembled boards, programming the microcontroller and putting it all together in its case.

We'll also have some performance measurements and instructions for using the finished unit. SC

434MHz LoRa Transceivers



This month we're looking at two LoRa modules based on the SX1278, a complete wireless data modem/transceiver capable of data rates up to 300kbit over modest distances in the 434MHz band. These can be controlled from a micro using an SPI or UART serial interface.

Connecting a couple of computers, Arduinos, Micromites or other micros via a UHF wireless data link is easy if you use a pair of low-cost modules based on the SX1278 ultra-low-power LoRa modem/transceiver chip. The SX1278 is made by Semtech Corporation of Camarillo, Southern California, which acquired the patented LoRa technology from French firm Cycleo in 2012.

The name "LoRa" is a contraction of "Long Range". It is a wireless technology developed to enable low power wide-area networks (LPWANs) for machine-to-machine (M2M) and Internet of Things (IoT) applications. The exact details of the technology are proprietary and closed, but it's apparently based on spread-spectrum modulation.

The SX1278 is designed to operate in the UHF spectrum between 410 and 525MHz. This makes it suitable for use in the 433.05-434.79MHz ISM (Industrial, Scientific and Medical) band which is available for license-free use in most countries. In Australia, this is called the LIPD (Low Interference Potential Devices) band.

The SX1278's data sheet can be found at siliconchip.com.au/link/aao3

Note that in Australia, the maximum transmitter power (EIRP – equivalent isotropically radiated power) for unlicensed devices in the LIPD band is 25mW or +14dBm. Transceivers with programmable output power will need to be configured to stay under this limit to remain legal.

There are two different SX1278-based LoRa modules currently available. One is the RA-02, designed by AI-THINKER, which is available from Banggood (siliconchip.com.au/link/aao7) and various other suppliers for around $6.60 each. The other is the E32-TTL-100 from eByte, also available from Banggood (siliconchip.com.au/link/aao8) and other suppliers for around $13.50 each.

So the RA-02 is around half the cost of the E32-TTL-100, and as you can see from the photos, it's also much smaller at just 16.5 x 16 x 3mm compared with 34 x 21 x 4mm for the E32-TTL-100, not including its SMA RF connector or its 7-pin SIL header. But the RA-02 has some disadvantages, too.

One of these is that the RA-02 module's tiny PCB is designed to be surface-mounted on another PCB. So instead of providing a pair of 8-pin SIL headers with standard 2.54mm pin spacings for power and control, it has a row of eight semicircular indentations along each side, with each one gold plated to allow soldering to matching pads underneath.

The spacing of the indentations is 2mm, so they do not line up with pads on the common 2.54mm (0.1-inch) grid.

Many constructors would therefore want to solder the module to an adaptor PCB, to bring all of the connections out to a pair of 8-pin SIL headers.

Another less attractive aspect of the RA-02 module is that its RF output/input connector is the extremely small U.FL-R-SMT coaxial type, with an outer diameter of only 2mm.

You will need a matching U.FL-LP plug to mate with it, which in most cases, comes as part of a complete antenna/cable assembly. It would not be easy to fit such a tiny plug to an existing cable.

So the RA-02 module is probably best suited for use in commercial type applications, especially those which will be assembled using automated pick-and-place equipment.

On the other hand, the E32-TTL-100 module is more suited for breadboarding, testing and manual assembly.

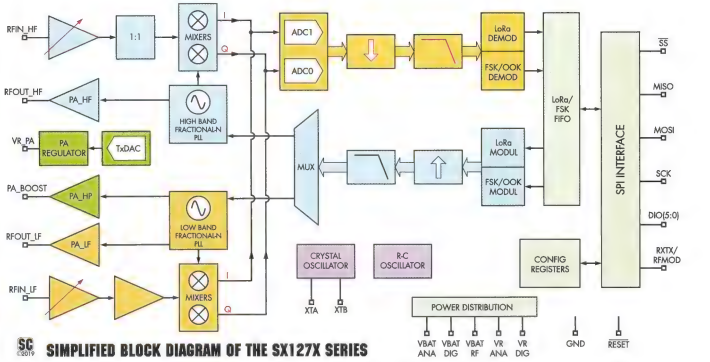


Fig.1: block diagram of the SX1276-SX1279 range of LoRa ICs. Even though there's an upper UHF front end shown in cyan, the SX1278 only uses the lower band (yellow) from 137-525MHz.

The RF input/output is via an SMA connector on one end of the module, with all of the remaining connections made via a seven-pin SIL header at the other end.

While we will focus on using the E32-TTL-100 module, we'll still provide a quick rundown on using the RA-02.

Since both modules are based on the SX1278 chip, let's start by looking at the chip itself.

Inside the SX1278

Fig.1, the simplified block diagram, shows what's inside that compact (6 x 6mm) 28-pin QFN chip. Note that this diagram covers all four of the different devices in Semtech's SX127X range, not just the SX1278.

The SX1278 is a single-chip UHF wireless data transceiver combined with a data modem capable of modulating and demodulating LoRa spread-spectrum signals.

But it supports other kinds of modulation too, including FSK (frequency-shift keying), GFSK (Gaussian FSK), MSK (minimum shift keying), GMSK (Gaussian MSK) and OOK (on-off keying).

The term 'Gaussian' in GFSK and GMSK signifies that the modulating data is passed through a Gaussian filter to make the transitions smoother before modulation. GFSK modulation was the original type of modulation used in Bluetooth, and is still used in BR (basic rate) Bluetooth devices.

Fig.1 shows the SX1278's SPI interface at far right, which allows it to be fully configured by a microcontroller.

Although two separate UHF front ends are shown at far left, one for HF and one for LF, the SX1278 only uses the LF front end as its specified frequency range is 137-525MHz. It can be programmed for a spreading factor of 6-12.

So the main sections of Fig.1 which are relevant to the SX1278 are the LF front end at lower left, with its fractional-N PLL (phase-locked loop) driving the two quadrature (I and Q) mixers, plus both sections of the fancy modem at top centre-right.

The modulator section is shown tinted blue, while the demodulator section is tinted orange.

The SX1278 can operate at data rates up to 37.5kb/s, but in the 434MHz LoRa modules, the maximum recommended rate is 9600 baud, or 2400 baud for maximum reliability.

The transmitter in the SX1278 has a rated maximum power output of 100mW (+20dBm), but can be programmed to provide lower output levels: +17dBm (50mW), +14dBm (25mW) or +10dBm (10mW). For legal use in Australia, the 25mW and 10mW settings are possible.

Reception sensitivity of the SX1278's RF front end is rated at -148dBm, which corresponds to about 10nV at the input. As a result, SX1278-based modules are often described as having a reliable communication range of 3km.

However, this assumes that they are set for an output power of 100mW, have a 5dBi gain antenna, a clear line-of-sight path between them and are operating at 2400 baud.

In Australia, with a maximum output power of 25mW (taking into account the antenna gain), this range drops to around 1.5km. And remember that this is for a clear line of sight path with a high-gain antenna and a data rate of 2400 baud. So in many cases, you'll be doing well to get a range of 1km, but that's still quite useful.

Despite its internal complexity and multiple functions, the chip is relatively economical in terms of power consumption. Operating from a 3.3V DC supply, it draws less than 100mA in transmit mode (at the 100mW setting), less than 13mA in receive mode and less than 2mA in standby mode.

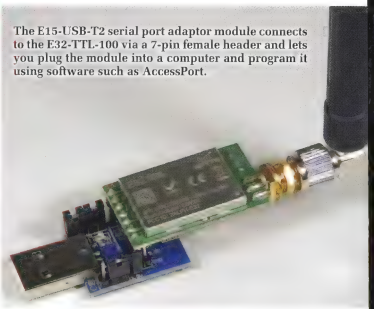
eByte's E32-TTL-100 module

As mentioned earlier, the E32-TTL-100 has a UART/USART serial

TABLE 1: E32-TTL-100 LoRa MODULE SETUP & USE

MODE	FUNCTIONS
MODE 3: SLEEP & SETUP (M0 & M1 AT LOGIC HIGH, E15-USB-T2 JUMPER SHUNTS OFF)	SET & CHECK MODULE PARAMETERS & FIRMWARE: 1: SEND HEX PACKET [C0 00 00 1C 18 46] TO SET MODULE PARAMETERS 2: SEND HEX PACKET [C1 C1 C1] TO REQUEST SAVED PARAMETERS 3: MODULE SHOULD RESPOND WITH THIS PACKET: [C0 00 00 1C 18 46] 4: SEND HEX PACKET [C3 C3 C3] TO REQUEST MODULE'S FIRMWARE CODE 5: MODULE SHOULD RESPOND WITH A PACKET SIMILAR TO THIS: [C3 32 44 14]
MODE 0: NORMAL COMMS MODE (M0 & M1 AT LOGIC LOW, E15-USB-T2 JUMPER SHUNTS ON)	SEND & RECEIVE ASCII TEXT & DATA VIA LoRa WIRELESS LINK

NOTE: Ensure that an antenna is connected to module before switching to Mode 0



The E15-USB-T2 serial port adaptor module connects to the E32-TTL-100 via a 7-pin female header and lets you plug the module into a computer and program it using software such as AccessPort.

interface. This is provided by an ST-Micro 8L151G 8-bit ultra-low-power microcontroller that's inside the 21 x 18 x 2.5mm shield on the top of the PCB, along with the SX1278 chip.

The result is that it's somewhat easier to program and use this module, as we'll see shortly.

We couldn't find an internal circuit diagram for the E32-TTL-100 module, but there is a 14-page data sheet available for the module which describes how to program and use it: siliconchip.com.au/link/aao4

The simplest way to use the E32-TTL-100 module is to hook it up directly to a PC via a CP2102-based USB-to-UART bridge. eByte makes a custom bridge module for this job, called the E15-USB-T2 serial port adaptor.

Measuring just 26 x 20mm, this PCB has a type-A USB plug at one end and a 7-pin SIL socket in the centre, into which the E32-TTL-100 module can be plugged (see photo above).

The E15-USB-T2 adaptor module is available from AliExpress, Alibaba and other suppliers, for less than $3.50. It has a 3.3V regulator on the underside plus a 3-pin SIL header on the top to allow you to select either 5V or 3.3V as the supply for the E32-TTL-100 module using a jumper shunt.

You can find four page data sheet on the E15-USB-T2 at www.cdebyte.com/en/pdf-down.aspx?id=761

There's also another pair of 2-pin SIL headers with jumper shunts to allow the voltages on the E32-TTL-100 module's M0 and M1 mode select pins to be set to either logic high or low. There's even a pair of tiny SMD LEDs, indicating its status. Fig.2 shows how the E32-TTL-100 and E15-USB-T2 modules connect together.

Note that if your PC doesn't have a VCP (virtual COM port) driver already installed for CP2102 based bridges, you'll need to install one to use this device (Windows 10 usually has this pre-installed). This driver can be downloaded from the Silicon Labs website (siliconchip.com.au/link/aalb).

You can then program the module and communicate via the LoRa modules is by using a serial monitoring application like AccessPort 1.37. This can be downloaded free from https://accessport.en.lo4d.com/ Once installed, it provides a very intuitive way to either send or receive data to/from the E32-TTL-100 module.

You can communicate using either hexadecimal numbers or text characters; it's best to use hex codes during the initial set-up (with the M0 and M1 jumpers on the E15 bridge module unplugged), and then text characters for normal airborne communication (with the M0 and M1 jumpers fitted). Table 1 is a summary of the basic E32-TTL-100 set-up steps.

Once the module is set up, connect a suitable antenna to the SMA socket and then fit the M0 and M1 jumper

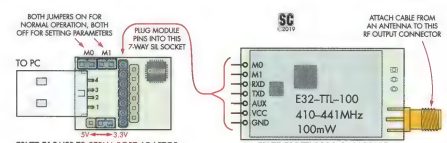
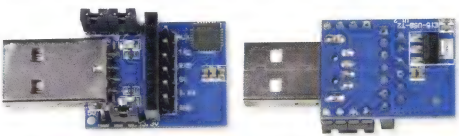


Fig.2: connection diagram for the E15-USB-T2 and E32-TTL-100 modules. Attaching only jumper M1 puts the module into power-saving mode (closes RXD), while only M0 starts wake-up mode (opens RXD).



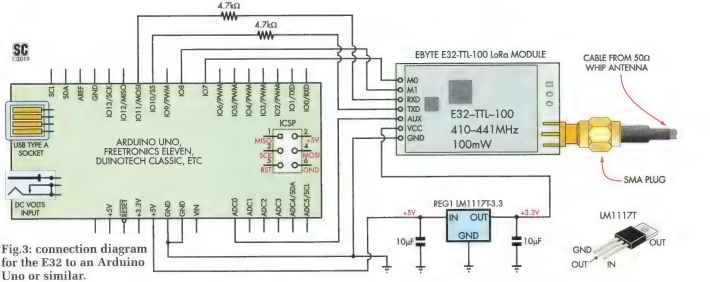


Fig.3: connection diagram for the E32 to an Arduino Uno or similar.

shunts back to the E15 bridge module, to switch the E32 module into Mode 0. You need to do it in that order, because the E32 module can be damaged if it's switched to Mode 0 before an antenna is connected.

Selecting an antenna

If you're not aiming for maximum range, you could use one of the low-cost 'rubber ducky' antennas with an integrated 90° SMA plug on the bottom, as shown in one of the photos. Go for one of the longer ones if you can.

Alternatively, you could use one of the longer 'loaded whip' antennas fitted with a magnetic mounting base and a 1.5m-long cable ending in an SMA plug. These antennas are around 210mm long including the loading coil, and are claimed to have an SWR of less than 1.5 at 433MHz, together with a gain of 3dBi.

However, this would not be legal to use with the 25mW output power setting as it would exceed the unlicensed EIRP limit. You could only use it with the 10mW power setting, which would reduce power consumption but also give you shorter range than the 25mW setting with a quarter-wave whip.

Loaded whip antennas are available from a few different suppliers on the web, including Banggood, which currently has them for about $5. Ensure you get one fitted with a standard SMA plug, not one with the more common RP-SMA (reversed polarity) plugs. The standard plug has a centre pin to match the centre hole in the module's SMA socket.

Connecting it to an Arduino

Using the E32-TTL-100 module with an Arduino Uno or similar is fairly straightforward, as you can see from Fig.3.

An LM1117T-3.3 regulator is used to derive the module's 3.3V supply from the Arduino's 5V line, because when it's transmitting, the module can draw peak currents of over 100mA, which is too much for the Arduino's onboard 3.3V regulator.

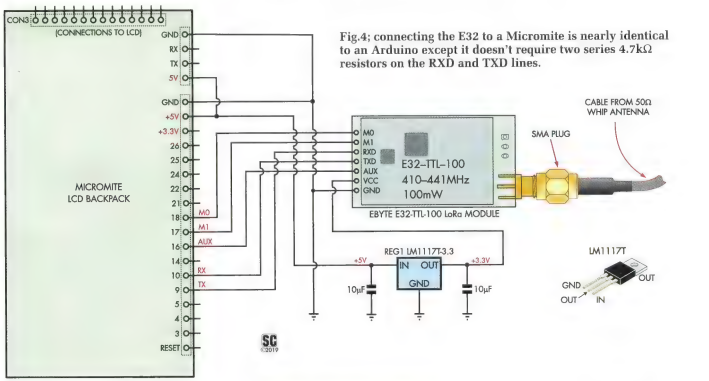


Fig.4; connecting the E32 to a Micromite is nearly identical to an Arduino except it doesn't require two series 4.7kΩ resistors on the RXD and TXD lines.

Notice also that the module's RXD and TXD lines are connected to Arduino pins D11 and D10 via 4.7kΩ series resistors, to prevent any voltage over-swing problems.

In terms of software, you'll find Arduino libraries as well as self-contained sketches on sites like GitHub (https://github.com/Bob0505/E32-TTL-100). However, I ended up writing my own self-contained sketch called "Uno_sketch_for E32_TTL_100_LoRa_module.ino", which can be downloaded from the SILICON CHIP website.

Using it with a Micromite

Connecting an E32-TTL-100 module up to a Micromite is again fairly easy, using the connections shown in Fig.4. Once again we're using an LM1117T-3.3 regulator to derive the module's 3.3V supply from the Micromite's +5V line, for the same reason as stated above.

We're using a 'software' serial port on the Micromite to communicate with the module, to prevent any unforeseen interactions with the Micromite's hardware (UART) serial port, which is used to communicate with the PC. That's why the module's RXD and TXD lines connect to pins 9 and 10 of the Micromite, instead of to the TX and RX pins.

I couldn't find any pre-written Micromite programs to control and exchange data with the E32-TTL-100 module, so I had to write one. The resulting program is called "E32TTL100 LoRa module driving program.bas", and is available for download from the SILICON CHIP website.

Both programs are fairly simple. They set up the E32-TTL-100 module for legal use in Australia, then switch it to Mode 0 for airborne data communications. It should provide a good starting place for writing fancier programs of your own.

You're not restricted to using this program for LoRa communication between two Micromites. Since it sets up the E32-TTL-100 module in precisely the same way as does the Arduino sketch (or the PC/USB/AccessPort approach, for that matter), all three versions can communicate with one another.

This means you can have a module connected to a Micromite communicating with another connected to an Arduino, or to another plugged into the USB port of a computer.

See the E32-TTL-100 tutorial at siliconchip.com.au/link/aao5

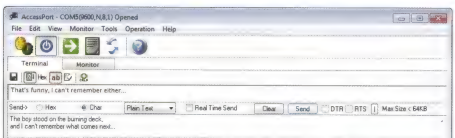
What about the RA-02 module?

As mentioned earlier, while the RA-02 LoRa module (siliconchip.com.au/link/aao6) is significantly lower in price than the E32-TTL-100, it is more difficult to solder and also needs an antenna fitted with a tiny U.FL-P connector. Also, you have to interface with the RA-02 via SPI as it does not have an SPI/UART bridge like the E32-TTL-100.

Regardless, use of the RA-02 with an Arduino seems to be popular, and you will find several Arduino libraries and sketches written to support it. One popular Arduino library is written by Sandeep Mistry: https://github.com/sandeepmistry/arduino-LoRa

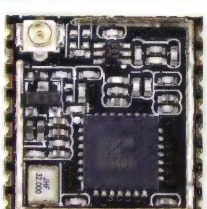
Before we could try out the RA-02 modules, we had to order some adaptor boards. The module is surface mounted onto these adaptor boards, and pin headers can then be soldered along the edge, so it will plug into a breadboard or another PCB using two header sockets.

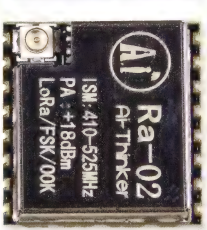
These adaptor boards are available at low cost from AliExpress (www.aliexpress.com/item//32825376146.html). You can also purchase similar



Above: example screenshot of the output from AccessPort when connected to an E32-TTL-100.

The RA-02 can be mounted onto a simple SMD adaptor board so that it can be easily attached to an Arduino etc.





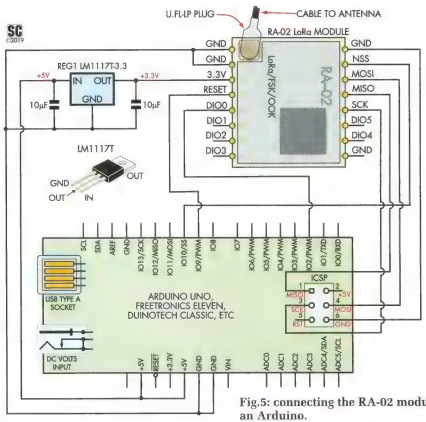


Fig.5: connecting the RA-02 module to an Arduino.

boards with the RA-02 module already soldered to them (www.aliexpress.com/item//32824507293.html).

We didn't have any luck finding a suitable 434MHz whip antenna already fitted with a cable ending in a U.FL-P plug. But we were able to get hold of a couple of adaptor cables with an SMA socket on one end and a U.FL-P plug on the other (www.aliexpress.com/item//32467389771.html).

The adaptor cables are sold together with 800MHz whip antennas fitted with an SMA plug, for around $1 each (plus $7 delivery to Australia!). After discarding the useless (to us) 800MHz whip, we used these adaptor cables to connect one of the 'loaded whip' antennas mentioned earlier to the RA-02 modules. Problem solved!

Fig.5 shows how to connect the RA-02 to an Arduino Uno while Fig.6 shows the connections for a Micromite. The configuration shown in Fig.5 suits Sandeep Mistry's library; you might need to change it if you're using a different library.

In both circuits, the RA-02 module receives its 3.3V supply from a 3.3V LDO regulator, fed from the micro's 5V output. Although the current drawn by the RA-02 is significantly lower than that of the E32-TTL-100, it still draws enough when transmitting to cause problems if powered directly from the micro module's 3.3V output.

With this arrangement, we made two Arduinos communicate via RA-02 modules using Sandeep Mistry's library. However, this does not work if you replace one of the RA-02 modules with an E32-TTL-100 module, even when both have been set to operate at 434MHz. So you need to use the same type of LoRa module at either end.

Our example sketch is named "SCLoRaSend_and_Receive.ino" and this is available for free downloading from the Silicon Chip website.

We have also written a similar Micromite MMBasic program, called "RA02 LoRa module checkout prog.bas", available on the Silicon Chip website. Using this, we were able to get two Micromites to communicate via RA-02 modules, and also exchange data between an Arduino and a Micromite using two identical RA-02 modules. SC

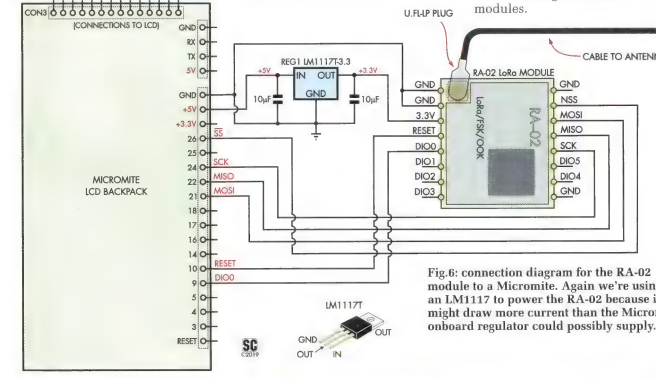


Fig.6: connection diagram for the RA-02 module to a Micromite. Again we're using an LM1117 to power the RA-02 because it might draw more current than the Micromite's onboard regulator could possibly supply.

CIRCUIT NOTEBOOK

Interesting circuit ideas which we have checked but not built and tested. Contributions will be paid for at standard rates. All submissions should include full name, address & phone number.

Touchscreen clock radio using a Micromite BackPack

Commercial clock radios are awful. The cheap ones can't even keep the time accurately. If you spend a bit more, you get accurate time, and may even get battery backup, but the sound quality is still horrible and they often don't have basic features like dimming.

They also use 1980s style 7-segment displays. You need to spend a lot of money to get one with decent sound quality.

This clock radio has very accurate timekeeping, battery backup, temperature measurement, an FM stereo tuner with a powerful stereo amplifier and stereo speakers.

It has automatic dimming, eight station presets and is very power-efficient. It features a colour touchscreen with nice fonts for the clock, making it easy to set the clock and program the presets.

It is based around the Micromite LCD BackPack V2, although I used the original BackPack board and added the new backlight circuitry.

The circuit is very simple because it makes use of four modules that can be cheaply purchased from eBay or other similar sites.

The first one is an LM2596-based DC-DC converter (MOD4). Initially, I used a linear regulator, but the voltage drop from 12V to 5V and the amount of current required to drive the backlight meant that it got very hot and wasted a lot of energy.

These modules are available from the SILICON CHIP Online Shop (**siliconchip.com.au/Shop/7/4916**). The module is adjusted using the onboard trimpot to give a 5V output.

The DS3231-based real-time clock module (MOD2) is extremely accurate and has battery backup and an internal temperature sensor that can be read through the I²C bus.

This is the same module that was used in the SILICON CHIP Super Clock project (July 2016 and updated in July 2018) and described in the October 2016 "El Cheapo Modules" article (**siliconchip.com.au/Article/10296**).

The modules are designed to use a rechargeable button cell and have a built-in charger circuit. This is bad for standard lithium batteries (CR2032), so the resistor just above the SCL label should be removed. This module is available from the SILICON CHIP Online Shop (**siliconchip.com.au/Shop/7/3519**).

The FM radio module (MOD3) is based on a TEA5767 IC. It is a PLL-tuned FM stereo receiver. It is very small and difficult to solder, but this can be made easy if a PCB is created with 10 pads to suit the module. It is also controlled using an I²C bus.

The stereo amplifier (MOD5) is quite small but contains a stereo Class-D amplifier which can deliver about 10W per channel. This seems like a lot of power, but small speakers suited to clock radios are really inefficient.

These two modules are available from the SILICON CHIP Online Shop (**siliconchip.com.au/Shop/7/5024** & **siliconchip.com.au/Shop/7/5025**)

The whole circuit is powered by a 12V switchmode plugpack. Only the amplifier module needs such a high voltage, so the DC-DC converter drops the voltage to 5V for the rest of the circuit.

The 3.3V regulator on the BackPack provides the 3.3V rail. To improve efficiency, the amplifier module is only powered when required, so its 12V power is switched by relay RLY1.

The FM radio module's analog outputs are fed to the amplifier module through a 4052 analog switch, IC1. This allows the micro to feed multiple different sound sources to the amplifier: either from FM radio, a stereo auxiliary input, the alarm sound from the micro or no source.

Sounds are fed to the amplifier module via 100nF AC-coupling capacitors. This relatively low value was deliberately chosen to limit the bass through the amplifier. Small speakers can go a lot louder if you don't try to get them to reproduce bass, and you don't need heavy bass when you wake up in the morning.

The amplifier output is fed into a crossover network before going to the speakers, to allow separate woofers and tweeters to be used. I used Jaycar Cat AS3034 3-inch woofers and some old ribbon tweeters that I had, although any small tweeter would be suitable.

The ambient light sensor is a light dependent resistor (LDR1). I used Jaycar Cat RD3485, although others could also be used. This forms a resistive divider with a 27kΩ fixed resistor and the resulting voltage is fed to an analog input on the BackPack module.

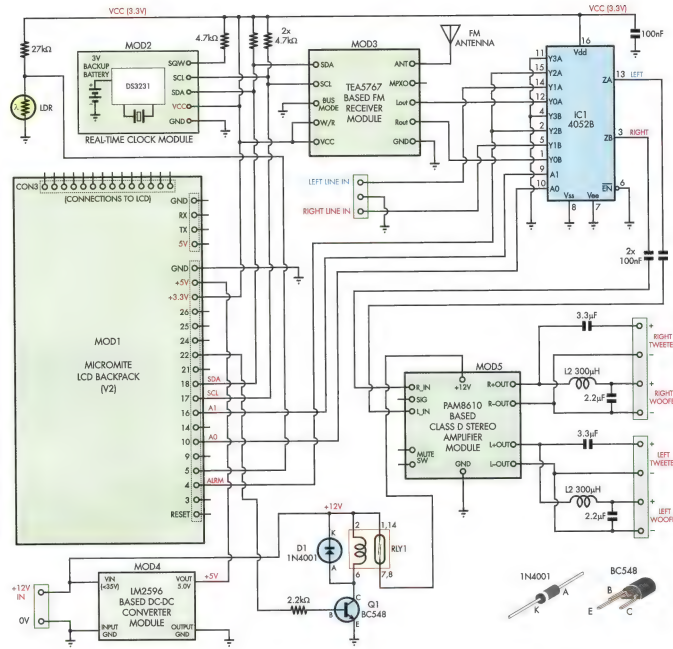
The software calculates an appropriate level of backlight brightness and updates the PWM duty cycle on pin 26. On the V2 BackPack, this controls the backlight brightness.

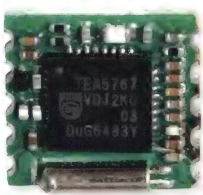
The Micromite has native support for the real-time clock module but additional code has been added to read the temperature. You can download the MMBasic source code for this project from the SILICON CHIP website.

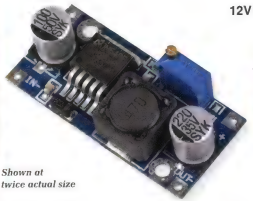
I originally tried adding a Bluetooth receiver to the circuit, but eventually gave up. There are many cheap Bluetooth receivers available both locally and from China that produce stereo signals that can be connected to the external input.

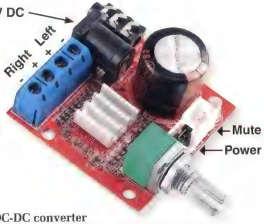
This circuit could be installed in an old stereo radio cassette or clock radio. I made a custom case from styrene, resulting in a very compact unit that only uses a small amount of space on a bedside table.

Dan Amos,
Macquarie Fields, NSW ($90).









Shown at twice actual size

From left to right: DS3231 RTC (MOD2), TEA5767 FM receiver (MOD3), LM2596 DC-DC converter (MOD4), PAM8610 Class-D stereo amp (MOD5). All these modules are available from the Silicon Chip Online Shop with product codes SC3519, SC5024, SC4916 and SC5025 respectively.

Two micros control an aircon with a single real-time clock module

Our lab has an air conditioner which is needed to keep the computer equipment at a reasonable temperature during summer.

But if we simply use the thermostat, it will run continuously on a summer's day and that is not required; we want a lower duty cycle than that. So I decided to build an Arduino-based timer to switch it on and off based on the time of day. But others in the lab want to be able to see the time and date display from this timer and also get an idea of when the air conditioner is to be switched on and off.

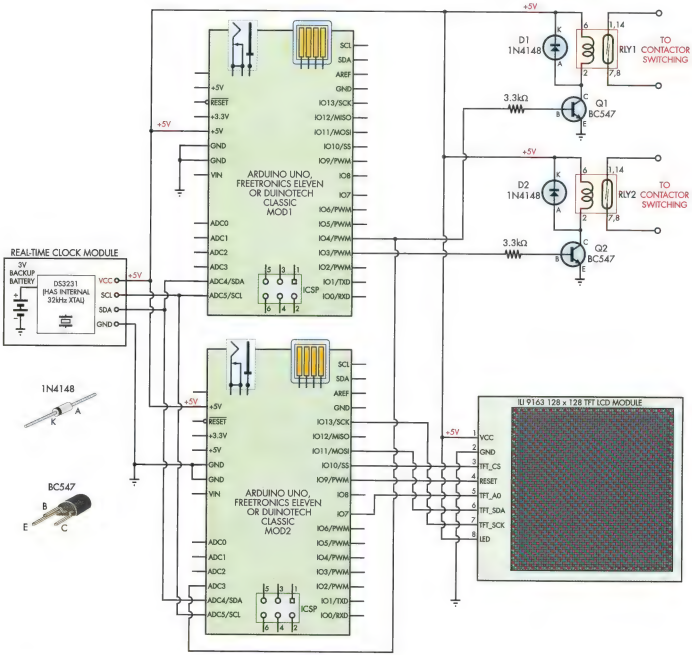
I found that difficult to incorporate into the timer software without interfering with the operation of the timer. So I used a second Arduino chip to drive the display and it reads the time and date out of the same real-time clock module.

So this project demonstrates how a single RTC module can be shared between multiple microcontrollers which are doing different jobs. I didn't want to use two separate RTC modules since there's no guarantee that they will not drift apart.

As the old adage goes, "a man with one watch always knows what time it is. A man with two watches is never sure."

The circuit is based on a DS3231 real-time clock module, two Arduino ATmega328 chips and two small 5V DC coil relays which drive the 5kW contactor that controls the air conditioner.

You can share the RTC module this way because the ATmega328's hardware I²C implementation supports the "multi-master" bus mode, which can handle the case when both devices want to use the bus at once – one will



wait for the other to finish before it takes over the bus.

The SDA and SCL pins of both masters are merely connected in parallel, and to the RTC module, and all the chips share a common ground.

The rest of the circuit is pretty simple; the DS3231 real-time clock module, the two ATmega328 chips and the 128x128 screen for time display all run from a shared 5V supply which is provided by a USB charger.

The LCD screen is driven by Arduino MOD2 over an SPI bus on the usual pins (D10, D11 and D13) plus a reset control line from digital output D9. Its backlight LED is powered directly from the 5V supply.

The D3 and D4 digital outputs of microcontroller MOD1 drive two NPN transistors which in turn, drive the coils of 5V coil mains-rated relays which control the air conditioner contactor.

The D4 output is also fed to the A3 input of the lower Arduino module (MOD2) so that it can monitor and display the contactor state.

The parts for this project (excluding the contactor) cost me around $10 from AliExpress.

Both Arduino sketches are available for download from the SILICON CHIP website. The download package also includes the three libraries required to build the sketches: Adafruit_GFX, RTC and TFT_ILI9163C.

Bera Somnath,
Vindhyanagar, India ($65).

Diode/transistor/Mosfet tester

This simple tester was devised to check that components in my junk box are still OK before I use them, using a single test board.

The transistor/diode tester section is based around hex inverter IC3. The IC3b and IC3c sections form an astable oscillator/multivibrator which runs at around 2Hz, set by the 1MΩ resistor and 100nF capacitor.

The outputs at pins 4 and 6 are 180° out of phase, ie, opposite in polarity. These voltages are buffered by parallel pairs of inverters, IC3a/IC3f and IC3d/IC3e.

The output from the IC3d/IC3e pair is fed directly to the collector of the device under test (DUT) and via a 56kΩ resistor to the base.

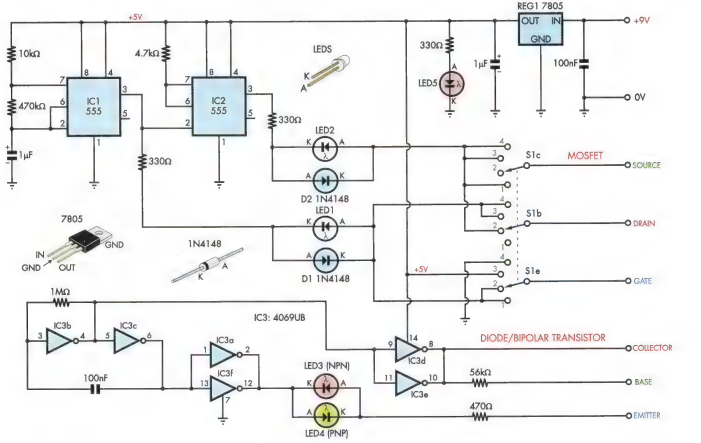
The emitter is driven with the opposite polarity signal from IC3a/IC3f via inverse parallel connected LEDs (LED3 & LED4) and a 470Ω current-limiting resistor.

If the DUT is working correctly then current will flow through either LED3 or LED4 during one of the output phases but it will cease during the other phase, when the base-emitter junction is reverse-biased.

So LED3 or LED4 will blink to indicate a good transistor, with the other LED remaining off. The colour indicates whether the transistor is a PNP or NPN device; red for NPN and green for PNP.

If the transistor has failed short-circuit then LED3 and LED4 will light alternately, whereas if it is open-circuit, neither LED will light.

Diodes can also be tested by connecting them between the COLLECTOR and EMITTER pin sockets. With a good diode, one of the two LEDs will blink while the other remains off. Reversing the diode will change which LED is blinking.



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The Mosfet testing section is based on two 555 timer ICs; a single 556 could be used instead. IC1 operates as an oscillator, again at around 2Hz, while IC2 operates as an inverter, giving a square wave at its pin 3 output that's opposite in phase to that of output pin 3 of IC1.

These two ICs drive the Mosfet terminals via 330Ω current limiting-resistors, white LEDs with reverse-connected diodes and rotary switch S1. S1 allows four different testing modes.

In position 1, the drain is left disconnected while the gate and source are driven with opposite phase signals via LED1 and LED2.

Since there should be a very high resistance between the gate and the other two pins, neither LED should light up. If either does, that indicates a short circuit between gate and source.

Similarly, in position 2, the source is left disconnected and the drain and gate are driven via LED1 and LED2. Again, neither LED should light up. If either does, that indicates a short between the gate and drain.

In position 3, the gate is connected to the 5V supply while the drain and source are driven with opposite signals via LED1 and LED2. If LED1 and LED2 light up alternately, that indicates that the Mosfet is an N-channel type. If it's a P-channel type, LED1 will remain off and LED2 will blink.

In position 4, the gate is connected to 0V (GND) while the drain and source are driven with opposite signals via LED1 and LED2. If LED1 and LED2 light up alternately, that indicates that the Mosfet is a P-channel type. If it's an N-channel type, LED1 will blink while LED2 will remain off.

If LED1 and LED2 light up alternately in both positions 3 and 4, that indicates a short circuit between the drain and source.

All of the ICs in the circuit are powered from a 5V regulated supply, derived from a 9V battery or plugpack by linear regulator REG1. LED5 lights up to indicate when power is applied. If using a battery, an on/off switch should be connected in series between it and the input of REG1.

Gianni Pallotti,
North Rocks, NSW ($70).

Editor's note: most Mosfets will work at 5V but some might not. The circuit supply voltage could be increased above 5V to make the Mosfet tester more reliable.

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VINTAGE RADIO

By Rob Leplaw

AWA Radiola Model 137

the "Fisk" recreated

Rob took an old radio chassis he inherited from his grandfather, fixed it and built a cabinet for it. The style is 1930s Art Deco, but with a less ornate and much smaller cabinet than the original. He had to repair or replace quite a few of the original components, and figure out how to get it working with few circuit details to go on. The result is a new-looking radio with the style and the sound of the 30s.

I first saw this radio chassis in my grandfather's shed in the late 1960s, while I was building a modified Austin A40. I eventually inherited the radio and over the years, I would see it sitting forlornly on the shelf in my workshop and would stop to take a look at it.

One day, I sat down and traced out a rough circuit. It became evident that someone had been into it and removed some parts. However, all the valves were there, and it looked like it might be salvageable. The labels indicated that it was Australian and the reason I kept it was it looked so old with all the 2.5V filament valves.

At the time, I was doing the Radio Trades course at North Sydney Technical College, so I scanned the library looking for circuits of radios with similar valves. But could never find an exact match.

Some years later, I had another burst of enthusiasm, as I noticed that the chassis was showing signs of decay from its years in a dusty shed. I then decided to strip the chassis carefully, remove the rust and paint it. Several years passed and now and then, I would again look at the radio and think I should find time to repair it. With that thought in mind, I usually just gave it a dusting and put it back in the plastic bag which had become its home.

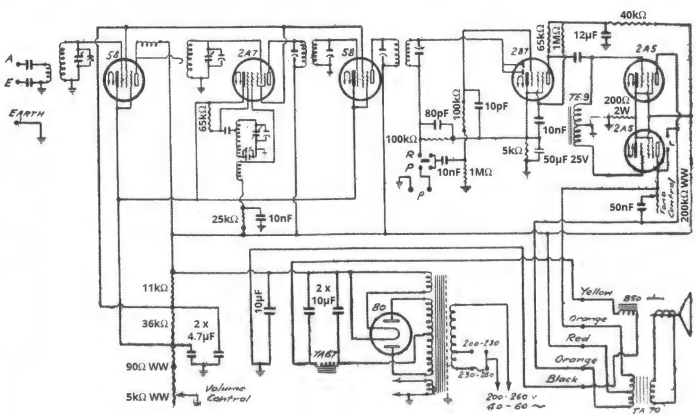
Finally, in 2016 I got serious. If I was going to get it working again, I had to nut out its circuit. But most of the large capacitors were inside metal containers, so I couldn't tell their value. I decided to open the containers and try to measure the individual capacitors. This involved using heat to melt the lid off and also to melt the wax inside, which held the capacitors in place.

A couple of the capacitors inside had markings but most didn't. I tried measuring them but they were all expired. Anyway, I had the basic circuit and of course, now we have the internet, so I started searching to see if I could find a circuit for a radio with the same valve line-up.

After much searching, I found details on the HRSA website of an AWA chassis that used precisely the same valves but no circuit diagram was available. It was the AWA Radiola Model 137 (1934).

I then found Kevin Chant's website and emailed him to see if he could help, but he turned up a blank.

While searching the web, I found circuit diagrams for AWA models 136 and 139, made just before and after my unit. Comparing the Radiola 136 circuit to my chassis, I could see it was a very similar design. However, mine



The AWA Model 137 is a mains powered radio with a 175KHz IF, an adjustable supply voltage of 200-260V AC and a safety fuse incorporated to protect against overload. The 36kΩ resistor near the volume control is a best guess value and not the actual value. A few of the components in the circuit haven't been labelled as their values are unknown.

has a push-pull output stage based on two 2A5 valves while the 136 used a single 2A5 in Class-A.

Finally, I decided to contact the HRSA and ask if they had a circuit for the 137. They did but it had no component values listed. I ordered a copy anyway and when it arrived, it was apparent that it matched my chassis. That circuit is shown here.

In my original circuit tracing, I had somehow transposed the RF input coil and the mixer coil, but apart from that, it very similar. The HRSA circuit showed that the output stage was driven by a centre-tapped transformer (missing from my chassis) and after discussions with HRSA members, I was advised about a suitable type of transformer to use.

I found the ideal period transformer on the internet and also an output transformer, as it was missing from my chassis.

Circuit description

This was a high-end set for its day, using seven valves; two type 58 pentodes, a 2A7 pentagrid, 2B7 double-diode pentode, two 2A5 pentodes and a type 80 (short for UX280) full-wave rectifier. The first type 58 is used as an RF amplifier stage, which feeds the 2A7 mixer/oscillator. From there, the signal goes to an IF amplifier stage based on the second type 58, then onto a dual diode/pentode (2B7) for detection and audio amplification.

The amplified, demodulated signal drives one of the 2A5 pentode output valves directly, as well as a phase-splitter transformer (labelled TE.9), which controls the other 2A5, so that they drive the centre-tapped primary winding of the output transformer in push-pull mode.

The type 80 full-wave (dual diode) rectifier is used to derive the HT voltage. This is filtered first by a pi filter involving an iron-cored choke (inductor), TA67, then further filtered using the electromagnetic speaker's 850Ω field coil. Thus the field coil gets its magnetising current from the HT while also providing the second inductor in the filter. This was standard practice in the days before permanent magnet speakers.

Note that the HT filter chokes are on the negative side. The positive HT rail voltage comes straight from the cathode of the type 80 rectifier valve, while HT ground first passes through the filter inductors (bypassed by three capacitors) before reaching the mains transformer.

Coupling from the RF amplification stage output (the anode of the first type 58 valve) and the tuned inductor circuit feeding the control grid of the mixer/oscillator is via air coupling, hence the strange 'hook-like' symbol seen between the two valves.

This is something you occasionally see in vintage radios. The output of the RF amplifier is strong enough to directly couple into the mixer circuit.

The volume control in this set may seem unusual, but it was common in earlier designs. The 5kΩ WW pot is in series with the common 90Ω cathode resistor for the RF amplifier, converter and IF amplifier. Their control grids are all DC biased to ground.

With the volume control at minimum resistance (maximum volume), a small amount of bias is created by the combined cathode currents flowing through the 90Ω resistor. As the volume pot is turned, its resistance rises, increasing bias to the three valves. This reduces gain, and thus volume. The volume control also adjusts the common screen bias voltage, via the 36kΩ/11kΩ voltage divider, although this has minimal effect on operation.

This would have been necessary since the set lacks AGC on the front end – there is no feedback path from

The underside of the chassis is quite neat. The silver cans marked 1-4 contain the coupling transformers, while the two copper boxes on the underside and top (left of the dial) of the chassis contain electrolytic capacitors.

the detector back to earlier stages. So the front-end gain had to be adjustable to avoid saturation on strong local stations.

The set also has a phono input socket and switch. The phono input is marked "P" and the switch marked "R" and "P", below and to the left of the 2B7 detector/audio preamplifier. In the "R" position, the signal from the demodulator is fed to the control grid of the 2B7 pentode, while in the "P" position, the demodulator is disconnected and the phono signal is fed in instead.

The demodulator has a 100kΩ load resistor to the 2B7's cathode and 82pF filter capacitor to remove the IF modulation. The 2B7's cathode resistor is bypassed with a 50μF capacitor to maximise gain. The audio signal from the R/P switch is further filtered by a 100kΩ/10pF RC low-pass filter, presumably to remove any remaining RF.

The radio also has a tone control pot. One end of its track connects to plate of one of the 2A5s (ie, one end of the speaker transformer primary) while its wiper is connected, via a 50nF coupling capacitor, to the anode of the other 2A5 and thus the opposite end of the speaker transformer.

So it seems that the tone control selectively shunts some of the amplified audio signals which would otherwise appear across the speaker. While this is an inefficient way to provide tone control, it was likely done to save on component count.

There is also a connector for an external loudspeaker, marked "L", shown just to the right of the 2A5s. It connects directly to the anodes of both 2A5s. One would hope that this terminal is well-insulated, given the high voltage which could appear across those two terminals.

Chassis restoration

After going over my chassis several times and comparing my components with those listed on the 136 circuit, I also discovered a few components had been removed from my chassis. I replaced all the unknown capacitors with values from the 136 or my best guess, and also changed a couple of resistors that measured a much higher resistance than expected.

The only big guess was the value of one resistor in the voltage divider that provides screen and biasing supplies to the RF & IF amplifiers and converter. The resistor in my chassis was open-circuit, and the colour code had flaked off.

The value in the Model 136 circuit seemed too low and didn't agree with the remaining paint on my resistor, so I guessed it was 36kΩ. It could have originally been 16kΩ but it works with 36kΩ, so I stuck with it.

Having replaced the missing components, it was time to power it up. First, I removed all the valves, so I could check the HT without them. I plugged the chassis in and switched on the power. Everything seemed to work OK, with the HT settling at 350V DC. This seemed a bit high, as all the valves list 250V as their plate voltage.

I worked out what the total current drain of the valves would be and calculated the expected voltage drop across the speaker field coil, and it looked like I would still have about 300V on the plates if I didn't make any changes.

So I added an extra load resistor across the HT supply to bring it down to 250V, just to be safe. I plugged in all the valves and switched it back on, monitoring the HT rail, and it settled down to 250V, as expected.

I fed an audio signal into the grid of the 2B7 audio preamp and got audio from the speaker. This was good but when I injected RF into the aerial input, I couldn't get anything from the speaker. The mixer was oscillating correctly and if I fed a signal into the mixer grid, I got an audio output.

After much head scratching, I decided to remove the inductor load on the RF amplifier's anode. As I pulled it out, I found that it had been shorted out with a piece wire wrapped around the back. That certainly explained the lack of output!

On closer examination, I found that the leads had broken off the load coil. I guess that is why it had been shorted

out, but that was a crude and not very effective repair attempt.

I managed to recover the wires at either end and repair the coil properly. With the working coil reinstalled, the radio sprang into life. I removed the additional load from the HT rail and it settled down to about 280V DC, and everything seemed fine.

But all the time spent in the old shed had done the speaker no good. The cone was utterly gone. I contemplated keeping the speaker field coil and fitting a modern permanent magnet speaker, but decided it would be better if I could repair the original, so I ordered a rubber surround on eBay that looked the right size.

When it came, I glued it in place and then made a new paper cone out of some construction paper. I carefully removed the remains of the old cone, being careful not to damage the voice coil wires, which I left surrounded by a small section of the old cone.

After adjusting and trimming the new cone to the right size, I glued it to the rubber surround and the voice coil diaphragm. I then connected the voice coil and the bucking coil to the new output transformer and reassembled the speaker. Back in the radio, it all worked perfectly!

As the chassis was found in a shed, the cabinet had apparently been discarded long ago. I had a picture of the original AWA cabinet (shown here); a huge piece of furniture. I was not keen to recreate that. So I browsed the internet, looking at pictures of vintage radios and eventually decided that I would build a tombstone style cabinet for it, with a rounded top.

The result would be a smaller, more practical and (in my opinion) more attractive package.

My original idea was to make a basic, plain face with the speaker at the top and I started construction with this in mind, making the cabinet as small as possible while still able to fit the chassis. Some way into the build, I saw an old Philips radio with a similar shape but a much more elaborate face and decided to style mine after it.

The base is made from recycled Australian cedar, as are the vertical pieces on either side, while the main part of the face is veneered in teak. The top arch is stained plywood. The badge in the middle of the speaker is a replica AWA Fisk Radiola.

I cut and shaped brass into a rounded rectangular shape for the dial feature. I had "Model 137" engraved under the dial opening. On the rear, I fastened an AWA employee badge that I found in a box of old badges.

Finally, it was finished, 48 years after I first laid eyes on it. When tuned to ABC RN and with music playing, it sounds very satisfying. SC

▲ The stations listed on the dial are, from left to right: 2CO, 7ZL, 3AR, 5CK, 4FC, 6WF, 5CL, 4QG, 3LO, 2BL, 4RK and 2NC. The only callsign still in use is 2BL.

◀ The new case is custom-built in an Art Deco style, and is much smaller than the original console cabinet (shown at right). The rear of the new case was affixed with an old AWA employee badge and a replica logo was made for the front.

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MICROPOWER LED FLASHER	OCT 2016	16109161	$5.00
MINI MICROPOWER LED FLASHER	OCT 2016	16109162	$2.50
50A BATTERY CHARGER CONTROLLER	NOV 2016	11111161	$10.00
PASSIVE LINE TO PHONO INPUT CONVERTER	NOV 2016	01111161	$5.00
MICROMITE PLUS LCD BACKPACK	NOV 2016	07110161	$7.50
AUTOMOTIVE SENSOR MODIFIER	DEC 2016	05111161	$10.00
TOUCHSCREEN VOLTAGE/CURRENT REFERENCE	DEC 2016	04110161	$12.50
SC200 AMPLIFIER MODULE	JAN 2017	01109161	$15.00
60V 40A DC MOTOR SPEED CON. CONTROL BOARD	JAN 2017	11112161	$10.00
60V 40A DC MOTOR SPEED CON. MOSFET BOARD	JAN 2017	11112162	$12.50
GPS SYNCHRONISED ANALOG CLOCK	FEB 2017	04202171	$10.00
ULTRA LOW VOLTAGE LED FLASHER	FEB 2017	16110161	$2.50
POOL LAP COUNTER	MAR 2017	19102171	$15.00
STATION/MASTER TRAIN CONTROLLER	MAR 2017	09103171/2	$15.00/set
EFUSE	APR 2017	04102171	$7.50
SPRING REVERB	APR 2017	01104171	$12.50
6GHz+ 1000:1 PRESCALER	MAY 2017	04112162	$7.50
MICROBRIDGE	MAY 2017	24104171	$2.50

PRINTED CIRCUIT BOARD TO SUIT PROJECT:	PUBLISHED:	PCB CODE:	Price:
MICROMITE LCD BACKPACK V2	MAY 2017	07104171	$7.50
10-OCTAVE STEREO GRAPHIC EQUALISER PCB	JUN 2017	01105171	$12.50
10-OCTAVE STEREO GRAPHIC EQUALISER FRONT PANEL	JUN 2017	01105172	$15.00
10-OCTAVE STEREO GRAPHIC EQUALISER CASE PIECES	JUN 2017	SC4281	$15.00
RAPIDBRAKE	JUL 2017	05105171	$10.00
DELUXE EFUSE	AUG 2017	18106171	$15.00
DELUXE EFUSE UB1 LID	AUG 2017	SC4316	$5.00
MAINS SUPPLY FOR BATTERY VALVES (INC. PANELS)	AUG 2017	18108171-4	$25.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER	SEPT 2017	01108171	$20.00
3-WAY ADJUSTABLE ACTIVE CROSSOVER PANELS	SEPT 2017	01108172/3	$20.00/pair
3-WAY ADJUSTABLE ACTIVE CROSSOVER CASE PIECES	SEPT 2017	SC4403	$10.00
6GHz+ TOUCHSCREEN FREQUENCY COUNTER	OCT 2017	04110171	$10.00
KELVIN CRICKET	OCT 2017	08109171	$10.00
6GHz+ FREQUENCY COUNTER CASE PIECES (SET)	DEC 2017	SC4444	$15.00
SUPER-7 SUPERHET AM RADIO PCB	DEC 2017	06111171	$25.00
SUPER-7 SUPERHET AM RADIO CASE PIECES	DEC 2017	SC4464	$25.00
THEREMIN	JAN 2018	23112171	$12.50
PROPORTIONAL FAN SPEED CONTROLLER	JAN 2018	05111171	$2.50
WATER TANK LEVEL METER (INCLUDING HEADERS)	FEB 2018	21110171	$7.50
10-LED BARGRAPH	FEB 2018	04101181	$7.50
10-LED BARGRAPH SIGNAL PROCESSING	FEB 2018	04101182	$5.00
TRIAC-BASED MAINS MOTOR SPEED CONTROLLER	MAR 2018	10102181	$10.00
VINTAGE TV A/V MODULATOR	MAR 2018	22104181	$7.50
AM RADIO TRANSMITTER	MAR 2018	06101181	$7.50
HEATER CONTROLLER	APR 2018	10104181	$10.00
DELUXE FREQUENCY SWITCH	MAY 2018	05104181	$7.50
USB PORT PROTECTOR	MAY 2018	07105181	$2.50
2 x 12V BATTERY BALANCER	MAY 2018	14106181	$2.50
USB FLUTTMER	JUNE 2018	19106181	$7.50
WIDE-RANGE LC METER	JUNE 2018	04106181	$5.00
WIDE-RANGE LC METER (INCLUDING HEADERS)	JUNE 2018	SC4618	$7.50
WIDE-RANGE LC METER CLEAR CASE PIECES	JUNE 2018	SC4609	$7.50
TEMPERATURE SWITCH MK2	JUNE 2018	05105181	$7.50
LitePOLOPS CONTROL SHIELD	JUNE 2018	11106181	$5.00
RASPBERRY PI TOUCHSCREEN ADAPTOR (TIDE CLOCK)	JULY 2018	24108181	$5.00
RECURRING EVENT REMINDER	JULY 2018	19107181	$5.00
BRAINWAVE MONITOR (EEG)	AUG 2018	25107181	$10.00
SUPER DIGITAL SOUND EFFECTS	AUG 2018	01107181	$2.50
DOOR ALARM	AUG 2018	03107181	$5.00
STEAM WHISTLE / DIESEL HORN	SEPT 2018	09106181	$5.00
DCC PROGRAMMER	OCT 2018	09107181	$5.00
DCC PROGRAMMER (INCLUDING HEADERS)	OCT 2018	09107182	$7.50
OPTO-ISOLATED RELAY (WITH EXTENSION BOARDS)	OCT 2018	10107181/2	$7.50
GPS-SYNCHED FREQUENCY REFERENCE	NOV 2018	04107181	$7.50
LED CHRISTMAS TREE	NOV 2018	15107181	$5.00
DIGITAL INTERFACE MODULE	NOV 2018	16107182	$2.50
TINNITUS/INSOMNIA KILLER (JAYCAR VERSION)	NOV 2018	01110181	$5.00
TINNITUS/INSOMNIA KILLER (ALTRONICS VERSION)	NOV 2018	01110182	$5.00
HIGH-SENSITIVITY MAGNETOMETER	DEC 2018	04101011	$12.50
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FOUR-CHANNEL DC FAN & PUMP CONTROLLER	DEC 2018	05108181	$5.00
ATtiny816 DEVELOPMENT/BREAKOUT BOARD	JAN 2019	24110181	$5.00
ISOLATED SERIAL LINK	JAN 2019	24107181	$5.00
DAB+/FM/AM RADIO	JAN 2019	06112181	$15.00
TOUCH & IR REMOTE CONTROL DIMMER MAIN PCB	FEB 2019	10111191	$10.00
REMOTE CONTROL DIMMER MOUNTING PLATE	FEB 2019	10111192	$10.00
REMOTE CONTROL DIMMER EXTENSION PCB	FEB 2019	10111193	$10.00
MOTION SENSING SWITCH (SMD) PCB	FEB 2019	05102191	$2.50
USB MOUSE AND KEYBOARD ADAPTOR PCB	FEB 2019	24311181	$5.00
REMOTE-CONTROLLED PREAMP WITH TONE CONTROL	MAR 2019	01111119	$25.00
PREAMP INPUT SELECTOR BOARD	MAR 2019	01111112	$15.00
PREAMP PUSHBUTTON BOARD	MAR 2019	01111113	$5.00
DIODE CURVE PLOTTER	MAR 2019	04112181	$7.50
FLIP-DOT COIL	APR 2019	19111181	$5.00
FLIP-DOT PIXEL (INCLUDES 16 PIXELS)	APR 2019	19111182	$5.00
FLIP-DOT FRAME (INCLUDES 8 FRAMES)	APR 2019	19111183	$5.00
FLIP-DOT DRIVER	APR 2019	19111184	$5.00
FLIP-DOT (SET OF ALL FOUR PCBS)	APR 2019	SC4950	$17.50
ICESTICK VGA ADAPTOR	APR 2019	02103191	$2.50
UHF-DATA REPEATER	MAY 2019	15004191	$10.00
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DSP CROSSOVER/EQUALISER DAC BOARD	**MAY 2019**	**01106192**	**$7.50**
DSP CROSSOVER/EQUALISER CPU BOARD	**MAY 2019**	**01106193**	**$5.00**
DSP CROSSOVER/EQUALISER PSU BOARD	**MAY 2019**	**01106194**	**$7.50**
DSP CROSSOVER/EQUALISER CONTROL BOARD	**MAY 2019**	**01106195**	**$5.00**
DSP CROSSOVER/EQUALISER LCD ADAPTOR	**MAY 2019**	**01106196**	**$2.50**
DSP CROSSOVER (SET OF ALL BOARDS – TWO DAC)	**MAY 2019**	**SC5023**	**$40.00**
STEERING WHEEL CONTROL IR ADAPTOR	**JUNE 2019**	**05105191**	**$5.00**
GPS SPEEDO/CLOCK/VOLUME CONTROL	**JUNE 2019**	**01104191**	**$7.50**

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ASK SILICON CHIP

Got a technical problem? Can't understand a piece of jargon or some technical principle? Drop us a line and we'll answer your question. Send your email to silicon@siliconchip.com.au

Tracking motor rotations

Has SILICON CHIP ever designed a circuit or discussed monitoring the voltage of a brushed DC motor to count its revolutions? I want to use a 12V DC motor like a crude stepper motor, to count its revolutions and stop it after a predetermined count.

This would be used to control the opening of a butterfly valve. It could open and then close fully when first powered up to establish a baseline, if required, although I would prefer if it could stay closed. (S. S., Manly Vale, NSW)

● The best way to do this is to add a rotation sensor to the motor shaft. This involves attaching a vane to the shaft that interrupts an optical pickup sensor or using an iron vane or magnet with a Hall effect sensor. The sensor produces a signal as the vane passes through the sensor. For a Hall effect sensor with a magnet, the signal would occur as the magnet passes by the sensor.

We show how to use an optical sensor for this purpose in the Contactless Tachometer described in the August and September 2008 issues (siliconchip.com.au/Series/52). Refer to Fig.6 in the August issue. Jaycar sells a suitable photo interrupter, Cat ZD1901.

They also have a suitable Hall effect sensor, Cat ZD1900. The data sheet can be downloaded from their website.

You could then use a microcontroller to monitor the output of either sensor and switch power to the motor off after a preset number of pulses (ie, rotations).

WiFi controlled dimmer wanted

The February issue is a beauty! John Clarke has produced a great project, as always, in the Touch and IR Controlled Trailing Edge Dimmer (siliconchip.com.au/Series/332).

In Circuit Notebook, Bera Somnath discusses the ESP-01 module with WiFi. Would it be possible to interface a WiFi module onto the Dimmer?

I could imagine a phone app being able to control all the lights in the house. Really smart software could evolve, say, to allow the phone's GPS position to notice you are approaching the house and switch on the welcome lights!

As always, the magazine is a great read, congrats Nicholas on keeping up a very fine product. (P. T., Montrose, Vic)

● That is indeed possible, but it isn't as simple as dropping an ESP-01 module into the dimmer. The ESP-01 draws a lot more idle current than the PIC used in the Dimmer, so it would need a much more substantial power supply, with either a transformer or switchmode module. The resulting device would be bulkier and harder to fit into a standard wall plate.

It would also require careful attention to avoid EMI problems between the mains supply and WiFI transceiver.

The infrared remote control feature is much simpler and provides a good compromise, since you can still control the lights when you're in the room, which is when you need them most!

Driving an I²C LCD screen from a PIC32

I am using the Micromite (PIC-32MX170F256B-50I/SP) and want to drive an LCD screen from it. Can the LCD in your Online Shop, Cat SC4203, be used with a PIC32?

What is the chip used in the LCD for I²C communication? What would the format of the signal from the PIC32 be? (F. T., via email)

● We published an article on how to drive I²C LCDs in the March 2017 issue, starting on page 82 (siliconchip.com.au/Article/10584). Here is a link to the software mentioned in that article, for the Micromite and also Arduino: siliconchip.com.au/Shop/6/4202

Although the article concentrates on 16x2 displays, the 20x4 displays use the same controller, a PCF8574, which provides the I²C interface.

If you order one of the screens from our Online Shop, it will come with either a PCF8574 or PCF8574A. The PCF8574A operates identically to the PCF8574 except that it responds to a different set of I²C bus addresses. See the March 2017 article for details.

Running sump pump from SILICON CHIP UPS

I recently built the UPS that was featured in the May-July 2018 issues of SILICON CHIP (siliconchip.com.au/Series/323).

It works extremely well; however, one of the reasons I built it was to provide power to a rainwater sump pump that pumps stormwater up from a pit on my premises to the road. If a power failure occurs while it is raining, the pit overflows and floods my garage.

The pump draws 800W when running and the UPS has no problems managing that load. The problem is that sometimes the pump will start, but most of the time it overloads the inverter at start-up which then shuts down. If I start the inverter manually and allow it to utilise its inbuilt soft start feature, the pump starts reliably every time.

I have built the Soft Starter project featured in the April 2012 issue (siliconchip.com.au/Article/705), but this didn't help, and in any case, I realised that as it will be powered on at all times via the UPS, it wouldn't do its job anyway.

This turned my thinking to whether or not the 1.5kW Induction Motor Speed Controller featured initially in April 2012 and revised in August 2013 (siliconchip.com.au/Series/25) might do the trick. As it is quite expensive, I thought I would seek feedback from you before proceeding, as there may also be other options.

Many thanks for producing such a great magazine. (D. E. Wattle Park, SA)

● The July 2012 Soft Starter for Power

Tools (siliconchip.com.au/Article/601) will provide soft starting in a situation where the mains supply is permanently connected to a device, and it switches on and off by itself. That design also has two thermistors in series so it may be more effective than the April 2012 Soft Starter.

But given the fact that your pump would rarely be running from the inverter, you would be better off simply purchasing several NTC thermistors similar to what was used in the Soft Starter and see how many you need to connect in series before the pump will start reliably on inverter power.

Assuming that this works, you could then mount them in a generously sized box (ideally a vented metal enclosure) with a mains plug and socket at each end. It would waste a bit of power as the thermistors would run hot while the pump is operating, but as long as they have enough air space, they should be OK.

The thermistors could be connected between the inverter and UPS switching relays, so that they are out of circuit when running from mains, as would be the case most of the time. They would only come into play on the rare occasion that the pump was running and mains power was absent.

Alternatively, it would be possible to modify the UPS design to leave the inverter off and switch it on when mains power had failed, and it detected that the pump wanted to start (via load sensing circuitry).

But that would add quite a bit of extra complexity; it would probably require a secondary 12V battery to run the electronics until the inverter started (and maybe a separate charger).

So we think you should try the thermistor approach first, as it's much simpler and may well do the job.

Building UPS using 12V battery and inverter

I want to build your UPS design from the May-July 2018 issue (siliconchip.com.au/Series/323) but using a 12V battery bank rather than the 24V bank that you used.

I assume that since the Arduino board and relays in your design run off a 12V supply, I could simply change the charger, inverter and batteries to 12V and then run these other components straight off the battery.

Obviously, the DC battery cabling would need to be upgraded to handle double the current. The reason I want to do this is that I already own a 12V, 20A charger, a 12V 32Ah battery and a 12V Giandel inverter.

My other question is: how well will the UPS kit handle a nearby lightning strike or another type of pulse on the mains? The Arduino could be the weak link here. (N. M., Yass River, NSW)

● The software should work without changes if you use a 12V battery instead of 24V, as the voltage thresholds can be set during the setup phase. However, the battery thresholds will need to be changed to suit.

The relays and Arduino board in our design are fed from a separate 240V-12V power supply, which is powered from the inverter output.

This is not just because we used a 24V battery bank; it was designed this way so that the load is totally removed from the batteries if the unit shuts down.

Running the Arduino and relays directly from the battery will change its behaviour; in particular, it will not be able to shut itself down entirely, as it will be powered even after commanding the PSU to turn off.

How the unit responds to irregularities on the mains will depend on the robustness of the individual components.

The sensing transformer and voltage divider resistors isolate the Arduino, and a brief surge should not cause any problems. It's designed to be able to handle higher voltages than it would usually be exposed to, anyway.

So we wouldn't expect the Arduino to be damaged except by a particularly bad spike or surge. You could add extra surge protection components (eg, a mains filter) if you are concerned or in a particularly lightning-strike prone area.

DCC Programmer not working with decoders

I have built the Arduino-based DCC Programmer (October 2018; siliconchip.com.au/Article/11261), and it works fine as a programmer. But when I tried to run it as a base station, it works with NCE decoders but will not work with Digitrax decoders. This is a problem as I have a mixture of these decoders.

Could this be a timing issue related to the 116µs pulse width? If so, is there any way this could be corrected? (G. P., Stafford Heights, Qld)

● There's no particular reason why the DCC Programmer should work with NCE decoders but not Digitrax. That it's working fine as a programmer

Which transformer to use with Universal Power Supply

I want to build your new Remote Controller Preamp with Tone Controls (March-April 2019; siliconchip.com.au/Series/333) using the recommended Universal Power Supply board. You haven't given a part number for transformer T1 in the parts list, and it is not shown on the circuit board. I guess it must be mounted off-board? Do you have a part number for it? (L. E. B., Beerburrum, Qld)

● You are right that the transformer does not mount on the Universal Regulator board. You will need to use a chassis-mounting transformer.

We didn't give a specific part number because there are many different transformers which could be used. For example, you could use a toroidal transformer, EI-core transformer or even an AC plugpack.

We recommend that you use a 15V or 15-0-15V (30V centre-tapped) transformer rated for at least 15VA to power the preamp via the Universal Regulator. Jaycar Cat MT2086 or Altronics Cat M4915B would be ideal.

If you want to save a bit of money, Jaycar Cat MM2008 and Altronics Cat M6672L are a bit cheaper, but will have more flux leakage than a toroidal type.

Jaycar Cat MM2002 and Altronics Cat M2155L are cheaper again, but you would only get half-wave rectification. That's probably good, but this will result in more ripple at the regulator inputs.

If you want to use a plugpack instead, try Jaycar Cat MP3021 or Altronics Cat M9325A.

suggests that the 116µs pulse width is not the problem. 116µs is well within the 100µs-10ms pulse width range specified in the DCC standards.

It's more likely that this has to do with the limited current that the 555 can supply, as mentioned in the article. Its absolute maximum value is 200mA, and it is already sagging quite badly at 100mA. It may be that the NCE chips handle the sagging voltage better, or don't need as much current to operate.

We published a DCC Booster design in the July 2012 issue which might help with this (siliconchip.com.au/Article/614).

We are also working on a DCC base station that will be capable of much higher current, so perhaps this is something you can consider building when we publish it.

Arduino Data Logger queries

I've finished assembling the Arduino Data Logger from your August and September 2017 issues (siliconchip.com.au/Series/316) and have a couple of questions.

Firstly, the colour coding for the GPS wires to CON3 is different between Fig.2 and the photo. The wiring is reversed in the photo. Both photos show the wire sequence to be red, blue, green, black and yellow, while Fig.3 shows the sequence reversed. Which is correct?

Also, upon trying to compile the supplied code, I get the following error:

```
Arduino_Data_Logger.ino:18:20:
fatal error: RTClib.h: No such
file or directory
```

It would seem that the real-time clock file hasn't been downloaded in the files from the SILICON CHIP web site. Thanks for the help, keep up the Arduino projects. (P. L., Tabulam, NSW)

● The photos in the August 2017 issue are of a veroboard prototype. You can tell because the PCB is red. The connector for the GPS in that version was installed rotated 180° compared to the final PCB. You can see photos of the final PCB in the September 2017 issue.

If you compare the photos of the final PCB to the overlay diagram, Fig.2, the colour coding for the wiring to CON3 is consistent.

Your compile error indicates that RTClib is missing. A zip of that library is included in the software download package.

Please make sure you have installed it before trying to compile the sketch, as per the instructions on page 32 of the August 2017 issue. Doing so should eliminate that error message.

Powering mic preamp from two 9V batteries

I am looking for a circuit of a coil microphone preamplifier circuit which can run from two 9V batteries connected in series. It can be transistor or op amp based. Have you published such a circuit in your magazine? (P. H., via email)

● We haven't published a circuit exactly as you describe, but we have published two microphone preamps which could be easily modified to run from ±9V rails produced by two batteries in series.

The first one is the Balanced Microphone Preamplifier (August 2004; siliconchip.com.au/Article/3585). The changes required are: omit REG1 and join its input/output terminals with a

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Cannot be used with an audio DVD Player

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wire link. Change the 16V supply rail bypass capacitors to 25V types. Connect the junction of your two batteries to the $V_{CC} \div 2$ split rail and then power the circuit from the 18V across the two batteries.

The second option is the Balanced Microphone Preamplifier & Line Mixer in the April 1995 issue. There is Altronics kit for this project still available (Cat K5531).

It's designed to run from ±12V, but it would work OK at ±9V. You would need to bypass the 12V regulators. Connect the junction of the two 9V batteries to the ground rail.

You can purchase a scan of that article at the following link: siliconchip.com.au/Shop/?article=5163 Note that the low-frequency response of this design can be improved from -3dB at 180Hz to -3dB at around 34Hz by increasing C7 from 100nF to 470nF.

Modifying amp power supply for lower voltage

I am building a kit for the 50W Audio Amplifier Module from the March 1994 issue of SILICON CHIP (Jaycar Cat KC5150). I want to use it to turn a passive subwoofer into an active subwoofer. The speaker impedance is 4Ω, and the instructions say to swap the LM3876T chip with an LM3886T chip and reduce the power supply rails from ±35V to ±28V.

Unfortunately, it doesn't say how to do that. I've been scouring the internet for help and can't find anything relevant. I've sourced an LM3886T but don't know how to modify the power supply circuit to get the required voltage. I need to know if it requires a different transformer and/or rectifier and the value of the required capacitors. (M. H., via email)

● For ±28V (nominal) supply rails you need a transformer with two 18V windings (18-0-18V or 36V centre-tapped). This will give you about ±25V at full load and about ±28V at light loads. The Altronics Cat M5118C 80VA toroidal transformer is suitable. You don't need to change any other components in the power supply.

Using Insulation Meter to test long cables

I purchased the June 2010 issue and the Power Supply PCB you designed to build a Digital Insulation Meter (siliconchip.com.au/Article/186). I built it and tested it on resistances from 500kΩ to 500MΩ at 500V, and it worked fine.

I then tested the meter on the same resistances but using 30m cables to connect the resistances to the meter. It worked OK below 10MΩ, but started giving incorrect results above that. For example, the reading was 190MΩ with a 100MΩ resistor at the end of a 30m cable.

I measured the current inside the cables, and it varied a lot more with long cables than with the short ones. I think this is due to the capacitance of the longer cables affecting the unit's operation.

I want to make insulation measurements on a cable a few kilometres long. Do you have any advice on how I can achieve this? (M. deR., Toulouse, France)

● The June 2010 Insulation Meter was not designed to check long cables. We think you're right that it's the cable capacitance that is causing the problems. Overcoming this might be tricky.

We suggest that you try fitting an additional LC filter between the output

Budget Senator Loudspeakers have more bass

I built both versions of the Senator Loudspeakers – the fully-fledged set using the Celestion drivers (September & October 2015; siliconchip.com.au/Series/291) and the "budget" set using the Altronics drivers (May & June 2016; siliconchip.com.au/Series/300).

I have used Jaycar-sourced inductors in the crossovers for both, after scouring the branches across Australia to get them.

I notice that the budget set sounds a little better than the original version with regards to the bass reproduction.

I have mounted the crossovers on the reflector plate behind the woofer in both versions and was wondering if this is correct, or should I have mounted them on the floor of the cabinets?

Both have the specified acoustic wadding but I noticed that in both instances, it covers the bass reflex port. Is this a problem? I have tried both sets of speakers being with the same Class-A amplifier and the same CD.

The cheaper set definitely has better bass reproduction and I'm wondering why. I love the magazine; keep up the good work. (P. C., Woodcroft, SA)

● We asked Allan about this and he responded: it is always pleasing to get feedback about my speaker projects!

In regards to the bass response, the Altronics C3065 driver does have a slightly lower resonance because of its softer compliance, but it also has a much lower power handling ability and sensitivity (60W/92dB) compared to the Celestion NTR10252OD/E drivers (250W/96dB).

The original Senator design is designed to handle 250W/channel. They can fill an auditorium and handle the heat because of the dual 2.5-inch voice coils used in the woofers. But if your room is small, then the budget speakers with the Altronics drivers will be fine.

I listen to the Celestion-based versions nearly every day for watching TV and movies and am amazed at their smooth response and big dynamics.

I never tire of the sound whereas I find the "budget" version a bit boomy in the bass. We all have different ears, so it becomes a personal choice which is better if high sound levels are not needed.

Your crossover mounting position is fine, and the wadding can be kept away from the port by rolling it up and loosely tying it up with a bit of thin insulated wire. But we don't think it will make too much difference either way.

Just check that all your cabinet joints are airtight because this can affect the bass response and you need to 'run in' the Celestions to get the best sound because of their tighter surrounds.

of the HV generator PCB and the 4.7kΩ/1W resistor connecting to the positive test terminal. This could use say a 470µH RF choke in series, together with a shunt capacitor arrangement to ground (after the RF choke).

This shunt capacitor arrangement would be a duplicate of the existing one at the output of the HV generator to ground – ie, a pair of 100nF/630V caps in series, each with a 10MΩ parallel resistor to ensure voltage sharing. This filter would help to isolate the cable capacitance from the HV generator.

It might also be a good idea to fit a 470µF capacitor in parallel with the existing 100nF capacitor connected between the negative test terminal and ground. We hope these suggestions help you to achieve your goals.

Running model railway at 24V

I am interested in building your Model Rail Controller (April 1997; siliconchip.com.au/Article/4890). I am building a garden railway with one locomotive which needs 24V. The 1997 design supplies 12V, and I like that it is simple. Can this project be upgraded to 24V? If so, do you still have this PCB available?

If this project can't be upgraded, do you have an alternative project? (I. S., Glenhaven, NSW)

- The Train Controller in the April 1997 issue actually runs from a split 12V supply. One 12V supply is for the positive (eg, forward direction) and the other 12V supply for the negative (reverse) direction. It is not easily adapted for a 24V supply, and the PCB is no longer available.

Instead, we suggest you build the Li'l Pulser Model Train Controller Mk2 (July 2013 & January 2014; siliconchip.com.au/Series/178). It can be powered from 24V. If the supply could exceed 24V then you will need to upgrade the input 2200µF supply decoupling capacitors to 35V types.

LED chaser kit wanted for tractor

Do you have a kit for a light chaser using LEDs that I could power from my Ferguson TEA20 tractor? I've fitted indicators, brake lights, headlights, and tail lights using 12V DC powered LEDs. (D. P., Young, NSW)

- We haven't published a light chaser in a long time, and the PCBs and kits for our older projects are no longer available. However, Jaycar sell the kits for Short Circuits projects, originally designed by SILICON CHIP, which includes at least three LED chasers.

The Jaycar Cat KJ8064 10 LED light chaser runs from 12V DC. They also have a 10-LED Knight Rider LED scanner kit, Cat KJ8236 and a 20-LED light scanner/chaser, Cat KJ8066. You can look up these catalog codes on their website for more information, including a link to the instructions for each kit as a PDF file.

Headphone amplifier sharing power supply

I am planning a revamp to build the Hi-Fi Stereo Headphone Amplifier (September 2011; siliconchip.com.au/Series/32) into an enclosure along with a multi-input preamplifiers. As the preamp runs from a ±15V supply, can I safely run the headphone amplifier from the same supply? (R. K., Cessnock, NSW)

- The headphone amplifier uses internal ±12V rails mainly for convenience, as this allows you to use a more common 12V AC plugpack power supply. You could run it from ±15V with little risk of overheating. The quiescent power would increase a bit and so the output transistors would run a bit hotter, but you could dial back the quiescent current slightly to compensate, if necessary.

Using switchmode plugpacks with valve preamp

I acquired some SILICON CHIP magazine back issues, including the vacuum tube based preamplifier designs incorporating switchmode power supplies, published in the November 2003, February 2004 and January/February 2016 issues (siliconchip.com.au/Series/293 and siliconchip.com.au/Series/295).

I can't find any mention of the type of 12V power source required, eg, linear "wall wart" or switchmode types. The linear (transformer-based) types with DC outputs are now hard to obtain.

The SMPS types are more abundant. Do you know if there would be any noise problems caused by using a switchmode plugpack with any of these designs?

Also, I read online that one constructor used the November 2003 power supply to power a stereo pair to good effect, then he says that he bought more PCBs, which are no longer available, only for some of the power supplies to fail without any reason. So I'm wondering if there may have been an update to the design in later issues.

I have been working in electronics design including vacuum tube audio, and I thought that if it worked for a year or so then the failure may have been to assembly flaws, dry joints etc.

I have made my own PCB but haven't powered it up yet. I believe it has to be loaded down with the tube circuit. Any help would be most appreciated. (J. H., UK)

- In both designs you've mentioned, the mains power supply feeds straight into the input of a linear regulator which should remove any noise.

That's why ~15V supplies were specified, to give the headroom for regulation down to 12V. The 2016 design was tested using a switchmode plugpack, and there was no sign of any digital noise getting through to the outputs.

There have not been any updates to either of these projects (except for the one you mentioned, in February 2004) and we are not aware of any problems with them. If it worked for a year and then failed, that suggests a faulty component. None of the components in these circuits are particularly stressed.

Neither power supply design should fail if operated without load, as they both have feedback-based voltage limiting. However, the January/February 2016 design does require the specified load to prevent 'squegging' which results in more noise appearing at the output.

We sell PCBs for all the projects that you mentioned. See siliconchip.com.au/Shop/?article=3390 & siliconchip.com.au/Shop/?article=9768 SC

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Coming up in Silicon Chip

12V Battery Isolator

This solid-state device automatically connects an auxiliary battery for charging when the vehicle alternator is running. It can handle charge currents in excess of 100A, does not get hot during operation, produces little to no EMI and has a low current drain when off.

Audio Millivoltmeter

This Arduino-based meter has three input ranges (200mV, 2V and 20V) plus balanced and unbalanced inputs. It provides an accurate audio signal level reading in µV/mV/V and dBV. It has better resolution than our previous designs, in a more compact package.

Micromite LCD BackPack V3

This new Micromite BackPack is still cheap and easy to build, but now supports larger touchscreens, plus has onboard provision for a real-time clock, temperature, pressure and humidity sensors, an infrared receiver and even more useful functions!

Rechargeable LED bicycle light

This device uses a switchmode converter to drive a string of LEDs from a rechargeable lithium-ion battery pack. It has multiple light modes and automatically reduces the LED current to prevent overheating.

Radiation and Electronics

The operation of electronics in aircraft and spacecraft (and here on Earth too) can be affected by radiation. It can even cause permanent damage. This article explores the sources of radiation that can affect electronics, what problems that radiation can cause and how to prevent or overcome those effects.

Speech Synthesis with Raspberry Pi and Arduino

Use a very low-cost Raspberry Pi Zero and this small add-on board to allow any computer or microcontroller to produce synthesised speech in a variety of languages and accents, and play back music and audio recordings. If you use a Pi with WiFi, it can even play internet radio streams.

Note: these features are planned or are in preparation and should appear within the next few issues of Silicon Chip.

The July 2019 issue is due on sale in newsagents by Thursday, June 27th. Expect postal delivery of subscription copies in Australia between June 25th and July 12th.

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Notes & Errata

DSP Active Crossover/Parametric Equaliser, May 2019: in the ADC circuit diagram on pages 30 & 31 (Fig.4), two pairs of 22µF capacitors are shown between the ±9V rails and ground but only one pair actually exists. Also, one 10µF bypass capacitor is shown on the +5V rail but there are actually two, with the other located close to IC4/IC5. Finally, the two 47µF coupling capacitors after FB1/FB2 are actually polarised, with the positive ends to FB1 & FB2.

Circuit Ideas Wanted

Got an interesting original circuit that you have cleverly devised? We will pay good money to feature it in Circuit Notebook. We can pay you by electronic funds transfer, cheque or direct to your PayPal account. Or you can use the funds to purchase anything from the Silicon Chip Online Store, including PCBs and components, back issues, subscriptions or whatever. Email your circuit and descriptive text to editor@siliconchip.com.au

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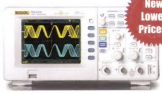

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